Caregiver touch and infant exploratory behaviour

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A thesis submitted for the degree of

Doctor of Philosophy

March 2021

DECLARATION OF ORIGINALITY

I, Alicja Brzozowska, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, it has been indicated in the thesis by citing the authors.

JOURNAL ARTICLES

This thesis includes research that appears in the following article:

Brzozowska, A., Longo, M.R., Mareschal, D., Wiesemann, F., Gliga, T. (2021). Capturing touch in parent– infant interaction: A comparison of methods. *Infancy*; 00:1– 21.

The work is cited in the relevant chapters accordingly.

ABSTRACT

Infants spend a lot of time in bodily contact with their parents; still, parents exhibit significant individual differences in the amount of touch they provide to their infants (Jean et al., 2009). Animal studies show that such naturally occurring variation in parental touching behaviours is consequential for infant development, in particular – response to novelty (Caldji et al., 1998). The amount of touch an infant receives might signal the quality of the environment to the infant, and thus the safety of engaging in exploration (Meaney, 2001). Moreover, there is growing evidence that affective touch also promotes social cognition in humans (Crucianelli & Filippetti, 2020).

Despite the strong premises to investigate the associations between caregiver touch and exploratory behaviour in human infants, few studies of these putative effects exist. This thesis aims to fill this gap by addressing the questions of whether the effects of naturally occurring variation in caregiver touch on exploratory behaviour found in non-human animals are indeed present in human infants, and what the mechanisms behind these putative effects are.

I start by investigating the different ways of measuring caregiver touch, and demonstrate that we are able to capture reliable individual differences in the use of touch even with one-off, self-report measures. I then go on to examine whether caregiver touch associates with infant oxytocin and cortisol levels, as possible mediators of the effects of touch on response to novelty. Next, I present an investigation into two components of exploratory behaviour, novelty approach and sustained attention, and examine whether caregiver touch predicts infant exploratory profile; I failed to find evidence for the hypothesised effects. Finally, I focus on infant social attention: no evidence for caregiver touch predicting overt social attention was found, but there was weak evidence for touch enhancing focused attention to faces, as measured with electroencephalography.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my supervisors: Prof. Denis Mareschal, Dr Frank Wiesemann, Prof. Matthew Longo and Dr Teodora Gliga. Before I started my PhD, I felt very intimidated by the prospect of working with such an incredible team of scientists. It did not take long until I realised that besides your scientific brilliance, you have brought so much kindness and humour to our collaboration. These past few years, I have felt very supported as a PhD student, and as a person.

Denis, your advice and encouragement have kept me inspired and optimistic about my scientific journey. Thank you for your and never-ending generosity of time and all the insightful discussions. Frank, I am very grateful for your guidance and the energy you have invested in our research. Your ceaseless enthusiasm for science is contagious and made it all possible.

Matt, thank you for your unwavering support. Your thoughtful feedback and advice have made me grow as a scientist.

Teea, I am truly grateful for your scientific passion, knowledge and all the times you have challenged my ideas only to improve them. You are a brilliant mentor and a role model.

I would also like to express my deepest gratitude to all the families who participated in the studies presented in this thesis.

I must acknowledge European Unions's Horizon 2020 Research and Innovation Programme under the Maria Skłodowska-Curie Grant Agreement no. 721895 for funding my research.

To my colleagues at Procter & Gamble German Innovation Centre, thank you for being so welcoming and helpful. I will always think fondly of my time in Schwalbach am Taunus because of you.

Thank you to everyone at the CBCD who provided advice, help and uplifting. Very special thanks to Isabel, Berta, Tamsin and Leslie for your support.

I would like to extend my thanks to my fellow PhD students, particularly my INTERLEARN mates: Cécile, Giada, Louisa and Susanne. To have shared parts of this experience with you made it so enjoyable.

Many thanks to Dr Laura Pirazzoli, who was the first person to show me how to do touch research with babies, Dr Elena Serena Piccardi, who provided advice on infant EEG, and Dr Ana Maria Portugal da Silva, who introduced me to eye tracking data analysis. Thank you to Dr Jannath Begum Ali for practical insights on infant testing, and to Dr Luke Mason for invaluable help with experimental scripts.

Thank you to Johanna Maninger and Sofia Soares for your help with video coding.

Finally, I am deeply indebted to my friends and family for supporting me throughout this journey. Moving between countries, surviving personal and global crises – your love and friendship made everything easier. Matylda, Asia, Maciek, Agata, Justyna, Gosia, Kacper, Nancy, Mara, Cierra: I am so thankful for you. Mum and Dad, thank you for being the most amazing parents, and always being there when I need you.

Babciu Helenko, Babciu Marysiu: dziękuję za Waszą miłość, wsparcie i poczucie humoru.

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Chapter 1

General Introduction

1.1. Chapter overview

Touch is the first sense to develop (Bremner & Spence, 2017), and an important means of contact between an infant and their caregiver (Hertenstein, 2002). Although the notion that caregiver touch plays a critical role in infants' healthy development is not a novel idea (Harlow & Zimmermann, 1959), touch has been a largely understudied topic in developmental science, compared with senses like vision and hearing. Recent years have seen an increased scientific interest in this means of interaction (Crucianelli & Filippetti, 2020), but many questions regarding the mechanisms and the extent of the impact of caregiver touch on infant development remain unanswered.

In this thesis, I examine the topic of the impact of caregiver touch on infant broadly-defined exploratory behaviour, and the possible mechanisms through which this impact could occur. To date, very few studies have investigated this specific topic – despite strong scientific reasons to do so.

The aim of the present chapter is to review the existing evidence for the effects of caregiver touch on infant exploratory behaviour, and to provide context for my own investigations presented in the chapters that follow.

Where does the hypothesis that caregiver touch affects infant behaviour come from? In the first part of this chapter, I discuss the origins of the overarching hypothesis of this thesis. I present the results of animal studies demonstrating effects of tactile stimulation on the ways in which animals engage with novel environments and objects. I then go on to discuss the relevance of these findings in the context of studies showing beneficial effects of touch on several domains of development in human infants.

How could caregiver touch affect infant exploratory behaviour? In the second part of this chapter, I cover possible functional and mechanistic explanations behind the putative touch-exploration effects. I discuss the hypothesis of touch acting as a signal of environment quality; following this hypothesis, I then go on to discuss the possible short- and long-term effects that touch could have on arousal and, in turn, infant exploratory behaviour.

How can we measure the mechanisms behind the putative touch-exploration effects? In the third part of this chapter, I focus on a particular avenue of touch research, which is also a significant part of this thesis – its effects on hormonal activity. I present the current state of knowledge about hormonal response to touch, focusing on two hormones: cortisol and oxytocin, as possible mediators of the effects of touch on infant response to non-social and social novelty.

What types of tactile stimulation from the caregiver might be most consequential for infant exploratory behaviour? The fourth part of the chapter is about the different types of tactile stimulation that have been the focus of scientific interest. I present the evidence on the particular significance of certain types of touch, and discuss the evidence in the context of possible effects on infant exploratory behaviour.

How much, or how little, caregiver touch has to occur to affect infant exploratory behaviour? In the fifth part of this chapter, I discuss the question of whether typically occurring variation in caregiver touch has effects on infant exploratory behaviour, or should we expect the effects to only occur as a result of atypical tactile experiences.

What is the developmental timeline of the putative effects of caregiver touch on infant exploratory behaviour? In the sixth part of the chapter I discuss the timing of the effects of touch on infant exploratory behaviour: when could caregiver touch shape infant exploratory behaviour? When can we study these putative effects?

Finally, in the last part of this chapter, I present the main aims and an outline of the thesis.

1.2. Origins of the hypothesis that caregiver touch affects infant exploration

1.2.1. Experiments with macaque monkeys

The classic studies by Harlow and colleagues from the 1950s and 1960s demonstrated the critical role of touch in development of infant macaque monkeys (Harlow & Harlow, 1962; Harlow & Zimmermann, 1959). Harlow separated newborn macaque monkeys from their biological mothers shortly after birth, and proceeded to conduct experiments investigating their attachment behaviours towards inanimate, surrogate mothers.[1] One of the surrogate mothers was covered in soft cloth, while the other was made of bare wire, but provided milk. At the time, the idea that infants form attachments to their caregivers based on the positive reinforcement provided by food was predominant. However, infant monkeys in Harlow's experiments generally spent much more time clinging to the soft cloth mothers than the wire mothers; moreover, the subgroup of monkeys raised only with bare-wire mothers exhibited serious emotional and physiological dysregulation. In his experiments, Harlow showed that comforting bodily contact was necessary not just for forming attachments between offspring and their caregiver, but also more generally for infants' well-being (Harlow & Harlow, 1962; Harlow & Zimmermann, 1959). Even though today the idea that caregiver touch is necessary for infant healthy development seems to be commonly recognised, at the time of Harlow's research this was not the case (Blum, 2002). Harlow's studies caused a significant increase in scientific interest in touch in infancy, and provided a base for future highly influential ideas in developmental psychology (Blum, 2002), including attachment theory (Bowlby, 1970).

[1] Harlow's experiments have raised many ethical concerns - see e.g. Blum (1994), Gluck (1997)

Even though Harlow's findings about the role of touch in caregiver-infant bonding might be the most well-known of his results, the implications of his research were more far-reaching. In particular, Harlow investigated how the presence and absence of caregiver touch affected infant monkeys' response to novel surroundings and unfamiliar objects. Infants raised with a soft-cloth surrogate mother, in comparison with infants raised with a surrogate mother made of wire, exhibited much less distress in a novel surrounding, much more approach behaviours towards unfamiliar objects, and spent more time manipulating the objects (Harlow & Zimmermann, 1959). Thus, caregiver touch was shown to regulate infant response to novelty, and promote exploration of the environment. Recently, Harlow's findings about the effects of comforting touch on exploratory behaviours were largely confirmed in an experiment where having received extra handling from a human caregiver for four weeks during the neonatal period was shown to promote a more positive response to novelty in baby macaque monkeys (Simpson, Sclafani, et al., 2019).

1.2.2. Experiments with rodents

The findings on the connection between caregiver touch and infant exploratory behaviour are further supported by a number of studies demonstrating comparable effects in rodents (Caldji et al., 1998; D'Amato et al., 1998; Liu et al., 1997). The rodent studies not only corroborated the findings from macaque research, but also provided insights into the mechanisms behind the associations between caregiver touch and infant exploratory behaviour.

In rats, tactile stimulation such as licking and grooming, as well as arched-back nursing (LG-ABN), is considered a basic nurturing behaviour necessary for offspring's healthy development (Caldji et al., 1998; Parent et al., 2017). Caldji et al. (1998) showed that the offspring of rat mothers who engaged in higher levels of LG-ABN behaviours showed significantly more exploration in an open-field test than the offspring of mothers who engaged in low levels of LG-ABN; in fact, there was a positive linear correlation between the frequency of maternal LG-ABN behaviours and the time rat pups spent exploring. Moreover, there was a significant effect of maternal LG-ABN behaviours on the development of neural systems implicated in response to novelty, in particular, the density of benzodiazepine and corticotropin-releasing hormone receptors (involved in stress response) in the locus coeruleus. In follow-up studies, it was discovered that maternal LG-ABN has far-reaching effects on the expression of many genes associated with stress reactivity and cognition (Caldji et al., 2004; Champagne et al., 2001; Kaffman & Meaney, 2007; Liu et al., 2000). LG-ABN was found to modulate infant hypothalamic-pituitary-adrenal (HPA) axis reactivity (Liu et al., 1997) and hippocampal development (Liu et al., 2000). The causal link between maternal touching behaviours and infant behavioural and neuroendocrine outcomes was confirmed in cross-fostering paradigms showing that when artificially assigned to be raised by high LG-ABN mothers, the biological offspring of mothers engaging in low levels of LG-ABN behaviours exhibited a phenotype characteristic of the biological offspring of high LG-ABN mothers (Liu et al., 1997, 2000). Moreover, a study in which licking and grooming behaviours in mothers were suppressed by benzodiazepine treatment showed that pups' exploratory behaviours also decreased (D'Amato et al., 1998; Kaffman & Meaney, 2007).

The macaque and rodent studies yielded powerful evidence that tactile stimulation from the caregiver shapes the development of exploratory behaviour in the offspring, and pointed to the specific neuroendocrine mechanisms involved. Importantly, they showed compellingly the presence of a causal link between tactile stimulation and offspring outcomes, controlling for possible genetic influences. In humans, studying the mechanisms through which caregiver touch affects infant development is more challenging, with more stringent ethical standards regarding both possible experimental manipulations, as well as available biomarkers. One of the possible experimental manipulations in human development research is examining the effects of touch based-interventions, where parents are asked to provide some type of additional tactile stimulation to their infants for a predefined period of time, and to contrast the developmental outcomes with the outcomes of infants who did not receive this additional tactile stimulation[2]. Studies on one particular touch-based intervention, Kangaroo Care, have yielded particularly interesting results.

1.2.3. Kangaroo Care and infant cognitive development – can animal studies help us explain the effects?

Kangaroo Care is an intervention where the parent holds their infant with ventral skin-to-skin contact (SSC), typically in an upright position and with the swaddled infant on the chest of the parent; it was originally introduced by Edgar Rey Sanabria in Columbia in 1978 (Campbell-Yeo et al., 2015). Kangaroo Care has mostly been implemented with low-birthweight infants born prematurely, as a medical intervention (Chan et al., 2016).

In their seminal work on the effects of Kangaroo Care (KC) intervention in infants born prematurely, Ruth Feldman and colleagues demonstrated its positive impact across several domains of development (Feldman et al., 2014). In their study, the beneficial effects of 14 consecutive days of Kangaroo Care provided in the neonatal period were measurable 10 years after the intervention; crucially, they pertained not just to domains previously shown to be affected by touch, like stress reactivity (e.g. Gitau et al., 2002; Mooncey et al., 1997), autonomic regulation (e.g. Field et al., 2006) and attachment behaviour (Weiss et al., 2000), but also to cognitive development. Feldman et al. (2014) showed that in the group of infants who had received KC, indices of executive functions at 5 and 10 years were significantly higher than in the control group. Earlier, at 6, 12, and 24 months, robust and significant differences in Mental Development Index (MDI) from the Bayley Scale of Infant Development (2nd edition) were observed; although, interestingly, no such differences were observed with regard to the Psychomotor Development Index (PDI). These findings not only demonstrate that the impact of tactile stimulation received early in development can be very long-lasting, but they are also, to my knowledge, the first ever evidence

[2] However, particularly in medical contexts, assigning study participants to control conditions might also raise ethical concerns; see e.g. Street & Luoma (2002) for a discussion.

that touch promotes not just emotional and social, but also cognitive development in human infants.

Yet, the mechanisms behind the effects of touch on cognitive development reported by Feldman et al. (2014) are not clear. How did the Kangaroo Care intervention administered in the first weeks of life cause what seems like a developmental cascade, affecting cognitive performance years after the intervention? Looking at evidence from animal research showing that caregiver touch affected exploration of novel objects and environments (Champagne & Meaney, 2007; Harlow & Zimmermann, 1959; Simpson, Sclafani, et al., 2019), it seems plausible that it was the effect of touch on early exploratory behaviour that subsequently caused the beneficial cognitive outcomes measurable in childhood.

Indeed, Bornstein et al. (2013) demonstrated a link between exploratory behaviour at 5 months and measures of cognitive performance collected as late as 14 years later. This finding points to the possibility that, if the effects of tactile stimulation on exploration found in other animal species also exist in humans, then caregiver touch could serve as a powerful tool contributing to the trajectory of a child's cognitive development. Considering the relatively low costs of potential touch-based interventions, demonstrating that these putative effects are indeed present in humans could open up new exciting possibilities of positively influencing both typical and non-typical development.

However, demonstrating the link between caregiver touch and infant exploratory behaviour would not be enough: ultimately, we would like to understand how touch could affect the ways in which infants engage with novel objects and environments. One functional explanation lies within the possibility that caregiver touch might act as a signal of environment quality.

1.2.4. Caregiver touch as a signal of environment quality

Michael Meaney, who was the primary investigator behind a lot of the studies showing the effects of maternal touch on offspring's stress response, emphasised that these effects have an adaptive function: depending on the quality of the environment, increased or decreased stress reactivity could be beneficial for the animal (Meaney, 2001). Indeed, nature and quality of the tactile stimulation that the mother gives to her child is highly dependent on the well-being of the mother, and therefore impacted on by a stressful environment (Humphreys et al., 2018). For instance, depressed mothers engage in fewer touching interactions with their infants (Ferber, 2004; Mantis et al., 2019). Thus, parental touch could act as a signal, indicating to the infant whether the environment they find themselves in is safe and rich in resources, with the caregiver readily available; this, in turn, could trigger a chain of physiological and epigenetic processes leading to decreased stress response to novelty and increased exploration. Conversely, in an unsafe and poor quality environment, sparse use of touch could prevent infants from engaging in risky modes of exploration and promote vigilant attention, thus serving a protective role (Gliga et al., 2019; Meaney, 2001; see Figure 1.1.).

Figure 1.1. Model describing the mediation of the effects of environment quality on infant stress by parental behaviours; based on Holochwost et al. (2020), McEwen & McEwen (2017) and Meaney (2001).

Remarkably, the effects of tactile stimulation on the expression of stress (both behavioural and as measured with cortisol levels) have even been demonstrated in fish (Schirmer et al., 2013; Soares et al., 2011). Fish are generally not considered a "social species" (De Waal, 2011; Schirmer et al., 2013); the presence of stress-buffering effects of touch in these animals suggests not only a possible non-social, bottom-up mechanism, but also indicates its phylogenetically very old origin (Schirmer et al., 2013; Soares et al., 2011).

These findings stand in seeming contrast to what was suggested by Meaney (2001) – could touch possibly signal the quality of the environment to a non-social, "primitive" animal like a fish? Yet, fish engage in exploratory behaviour (Baker et al., 2018), and it is conceivable that they could also employ tactile cues as indicators of environment characteristics. In the study by Schirmer et al. (2013), a water stream was used as the tactile stimulus; the authors point out that it could have signalled the presence of other fish and thus the safety of a shoal. This interpretation contradicts the claims of non-social origins of the stress-buffering effects of touch in fish (Soares et al., 2011), but is very much in line with the implications of rodent studies (Meaney, 2001).

The work of Meaney and colleagues provides a useful model for studying the impact of naturally occurring variation in caregiver touch on infant exploratory behaviour. Moreover, there is also evidence on potential effects of touch on response to specifically social stimuli via the effects of touch on the oxytocin system (Tang et al., 2020). Yet, much more research is needed – not only to validate the main premises of the model in human infants, but also to describe the mechanisms involved in more detail, accounting for the uniquely human aspects of touching behaviours, stress response, and non-social and social exploratory behaviour. Research on the neuroendocrine response to touch, particularly on two hormones, cortisol and oxytocin, could bring us one step closer to this goal. Both stress response approximated with cortisol measurements, as well as oxytocin system activity, assessed with salivary oxytocin, have been investigated in humans with respect to tactile stimulation. Below, I describe the mechanisms of hormonal response to touch in humans, and present the studies concerned with this topic.

1.3. Touch and hormonal response

1.3.1. Neural bases of hormonal response to social touch

Incoming touch and temperature (relevant particularly with regard to warmth-inducing touching interactions such as cuddling, holding etc.) pathways have access to the general neural circuitry involved in autonomic functioning, including maintaining stable relations between sympathetic and parasympathetic systems activity (see Morrison, 2016). Two basal forebrain nuclei involved in this circuitry play an especially crucial role in response to touch: the paraventricular nucleus (PVN), the main site of oxytocin release in the brain (Uvnäs-Moberg et al., 2014), and the arcuate nucleus (ARC) which is implicated in cardiovascular regulation (Sapru, 2013). The PVN and the ARC both send and receive projections to the nucleus of the solitary tract (NTS), which has been shown to have a regulatory influence on the (HPA) axis feedback loops – including one involving the corticotropin releasing hormone, which stimulates cortisol release (Morrison, 2016). The NTS receives temperature and touch signals from the spinothalamic tract, and core temperature information from the lateral parabrachial nucleus, and sends signals to the vagal nerve, influencing heart rate, and to sympathetic ganglia, influencing blood pressure (Morrison, 2016;

Zoccal et al., 2014). A schematic depiction of the subcortical circuitry involved in arousal response to touch is shown in Figure 1.2.

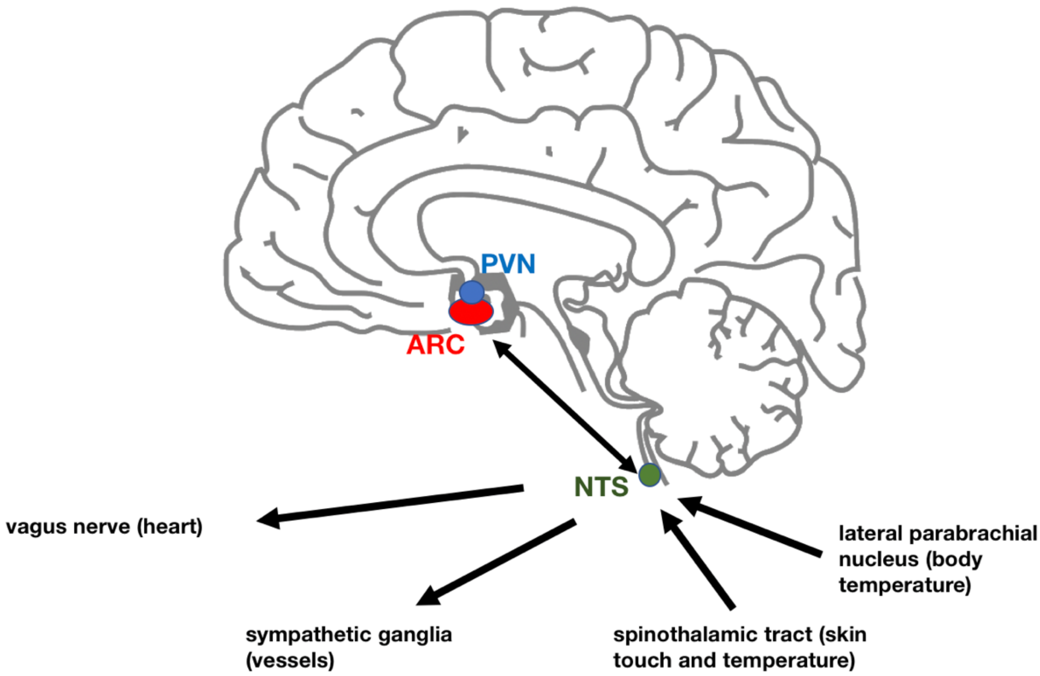

Figure 1.2. Depiction of subcortical structures involved in touch-related responses as well as a range of regulatory signalling influencing autonomic responses and other bodily systems; NTS – nucleus of the solitary tract (green), ARC – the arcuate nucleus (red), PVN – the paraventricular nucleus (blue); figure inspired by Morrison (2016)

Importantly, the aforementioned subcortical structures are directly and indirectly influenced by the neocortex – including areas implicated in social touch, such as the primary and secondary somatosensory cortices, insular cortex (involved not only in sensory and affective processing but also in high-level cognition in adults; Uddin et al., 2017) and right posterior superior temporal sulcus (pSTS, a part of the "social brain", as studied in childhood, adolescence and adulthood; Björnsdotter et al., 2014), adding further levels of modulatory control (Morrison, 2016).

However, it is important to note that while this functional neural network is established in adults, it may change across development. For instance, Pirazzoli et al. (2018) found that the activation in the pSTS in 5-month-olds in response to touch was not selective to affective touch, like it is in adults. This finding suggests that adult-like neural responses to touch may not emerge until later in development, which may be particularly true in case of phylogenetically newer structures (like the pSTS).

To conclude, the neural circuitry of touch-induced arousal response is complex and involves many feedback loops, including between the structures involved in cortisol and oxytocin activity. When studying hormonal response to touch it is therefore important to consider both low-level (e.g. temperature), as well as high level (e.g. social context) properties of tactile stimulation, and examine the possible interactions between the cortisol and oxytocin activity.

1.3.2. Touch and cortisol

Cortisol is a hormone associated with an organism's ability to respond to stressors and maintain homeostasis; its production is regulated by the HPA-axis (Mörelius et al., 2016). Salivary cortisol is commonly used as a biomarker of psychological stress (Hellhammer et al., 2009). High levels of cortisol under conditions of homeostasis (basal cortisol) indicate frequent and prolonged activation of the HPA axis (Gunnar & Fisher, 2006). Such dysregulation of HPA-axis activity has been found to increase the risk of cardiovascular disease, impair immune functioning and cause atrophy in the hippocampus and prefrontal cortex (J. D. Bremner & Vermetten, 2001; Holochwost et al., 2020; B. S. McEwen, 2006).

The associations between touch and cortisol response in adult humans are well documented, with social touch having been shown to act as a stress buffer (Eckstein et al., 2020; Morrison, 2016). Receiving hugs from a partner lowers heart rate and blood pressure, which are both indicators of arousal (Grewen et al., 2005).[3] Hand-holding decreases responses to stressors as measured with neural (Coan et al., 2006) and pupillary (Graff et al., 2019) activity. Massage (Listing et al., 2010; Maratos et al., 2017), but also self-reported physical intimacy with a partner (Ditzen et al., 2008) were found to lower salivary cortisol levels. Moreover, there are plenty of studies showing that touch by animals and robots has calming effects as well (see Eckstein et al., 2020 for a review). Even imagining touch support (vs. verbal support) before a stressful task (submerging hand in ice water) decreased self-rated stress levels during the task (Jakubiak & Feeney, 2016). These findings suggest that in adults, stress-buffering effects of touch are to large extent top-down driven, and affected by high-level properties of touch.

The stress-buffering effects of touch are also present in infants. For instance, evidence exists that in infants born prematurely, stress-reducing effects of touch provided in the first days of life can be observed. Gitau et al. (2002) found that maternal skin-to-skin contact provided for 20 minutes significantly reduced salivary cortisol levels in premature babies right after the period of stimulation. Mooncey and colleagues (1997) reported a similar effect of 60-minute-long skin-to-skin contact on premature infants' plasma cortisol levels. Similarly, Vittner et al. (2017) found that cortisol levels in premature newborns were significantly lower during skin-to-skin contact than immediately before, and 45 minutes after. Moreover, in a longitudinal study, Feldman et al. (2014) demonstrated that premature babies who received additional maternal skin-to-skin contact for as short as one hour per day for fourteen consecutive days in the neonatal period exhibited milder cortisol reactivity in a stressful situation 10 years later (as 10-year-olds) than their peers who had not receive such an intervention. Touch also seemed to attenuate the effects on cortisol response

[3] Hugging has also been found to decrease susceptibility to and severity of some upper respiratory illnesses: after exposure to a virus that causes a common cold, those study participants who reported having received more frequent hugs in the 14 days preceding the virus exposure were less likely to get sick, and if they did get sick, their symptoms were less severe (Cohen et al., 2015). Meanwhile, during the COVID-19 pandemic, the necessary social distancing measures implemented to prevent the spread of the virus, while having a protective effect, also resulted in many people being deprived of hugging, and other forms of social touch (Durkin et al., 2020).

of simulated maternal absence experienced in a still-face paradigm in 6-month-olds (Feldman, Singer, et al., 2010). In contrast, no effect of neonatal skin-to-skin intervention on cortisol response to intramuscular injection of a vaccine was found in premature infants at 4 months (Miles et al., 2006), meaning that perhaps the stress-buffering effects of touch do not extend to acute nociceptive stressors. Touch does, however, seem to affect HPA-axis activity both under conditions of homeostasis (Gitau et al., 2002; Vittner et al., 2017), as well as under conditions of stress or challenge (Feldman, Singer, et al., 2010; Feldman et al., 2014).

In light of this evidence, it is likely that naturally occurring high levels of caregiver touch would be associated with lower levels of basal cortisol and a dampened cortisol response to a stressor. Holding and cuddling could be especially relevant, given the similarities with Kangaroo Care in terms of physical sensations of deep pressure, which are commonly associated with feelings of calm and reduced anxiety in adults (Case et al., 2020; Morrison, 2016). Moreover, in 9-month-olds, stroking performed by a person caused a decrease in heart rate, which was more pronounced when the infant was made to believe the stroking was performed by their parent rather than a stranger (Aguirre et al., 2019). This finding implies a key role of social cues in physiological response to stroking in infancy. Social cues might also be particularly relevant when it comes to the levels of another hormone implicated in response to touch – oxytocin.

1.3.3. Oxytocin – the "love hormone"?

Oxytocin is a nine-amino-acid peptide, synthesised in the paraventricular nucleus (PVN) and supraoptic nucleus (SON) of the hypothalamus (Walum & Young, 2018). Known for its role in a variety of social behaviours, oxytocin has been especially implicated in those behaviours involved in forming and maintaining close relationships, of particular interest to us – touching.

Most of what we know about oxytocin comes from research done with non-human animals. The first animal which helped unveil the role of oxytocin in caregiving behaviours was the goat (Hammock, 2015; Klopfer & Klopfer, 1968). When studying the events at the time of parturition, Peter and Martha Klopfer observed that whether the goat mother would accept an offspring as hers was time-sensitive, and more dependent on internal changes in the mother than any external cues- the mother was happy to adopt and nurture both her own or what the Klopfers called an alien kid, if presented with the kid shortly after birth. This observation, combined with what was known about the physiology of labour at the time, led the scientists to formulate a hypothesis that it was the release of oxytocin happening during birth that mediated the mother-child bonding process (Klopfer & Klopfer, 1968). These researchers proposed that oxytocin activates "maternal centres" in the "hypothalamus or elsewhere", which would imply its specifically caregiving-related impact. However, they also acknowledged that oxytocin may act through a more general mechanism, altering "the thresholds of peripheral receptors so as to temporarily sensitise the doe to certain elements of the world" (Klopfer & Klopfer, 1968, p. 865). Since then, research with human participants has shown that following intranasal administration of oxytocin, men increase their gaze toward the eye region of human faces (Guastella et al., 2008), and women are better at inferencing internal states from facial expressions (Domes et al., 2007). In children aged 6 months to 8 years, a significant association between attention to the mouth and eye areas and salivary oxytocin levels has also been reported (Nishizato et al., 2017). Today, most scientists would agree that rather than being a special bonding or nurturing molecule, oxytocin acts more generally, through modulating the salience and reinforcing nature of social stimuli (e.g., Young, 2013).

Still, the "love hormone" label has stuck to oxytocin (e.g. Colaianni, Sun, Zaidi, & Zallone, 2015; Kodosaki, 2020), somewhat blurring its nuanced behavioural correlates. It is relatively well documented that baseline oxytocin levels in the caregiver predict their use of touching (Feldman & Bakermans-Kranenburg, 2017; Szymanska et al., 2017). Meanwhile, the evidence for touch leading to an increase in oxytocin in infants is unclear.[4] Below, I attempt to discuss what we know about oxytocin and touch; in Chapter 4, I specifically focus on human infant research.

1.3.4. Oxytocin and touch

1.3.4.1. Oxytocin and touch – insights from rodent research

It is worth reiterating that our understanding of the role of oxytocin is largely based on animal research, mostly done with rodents. It has been shown that in rats, administering oxytocin into the mother's brain ventricles (Pedersen & Prange, 1979) stimulated licking, grooming and arched-back nursing behaviour, whereas injecting an oxytocin antagonist into the ventral tegmental area and the medial preoptic area (MPOA) blocked it (Pedersen et al., 1994); these brain sites were identified as sites of oxytocin action on maternal behaviour.

The oxytocin-touch story is made more interesting by the later discovery of a two-fold relation between touch and oxytocin in rats: not only does oxytocin stimulate licking and grooming in the mother rat, but the more licking and grooming the pup receives, the higher the oxytocin receptor (OXTR) levels are in their MPOA. This, in turn, results in higher levels of licking and grooming of their own offspring (Champagne et al., 2001). This transgenerational mechanism was confirmed in studies using cross-fostering, a practice in which rat offspring of mothers engaging in low levels of licking, grooming and arched-back nursing (LG-ABN) are artificially assigned to be fostered by mothers engaging in high levels of these behaviours, and vice versa (Francis et al.,

[4] It is not uncommon to come across statements that touch leads to oxytocin increase in human infants, incorrectly citing studies that only reported oxytocin levels in caregivers (e.g. Markova, 2019; Van Puyvelde et al., 2019). This may be because, given the unique property of the sense of touch such that one cannot touch someone without experiencing touch themselves, the passive and active touching agents get conflated, leading to such misinterpretations.

1999), which allowed the researchers to conclude that it was indeed the tactile stimulation (and not any common genetic factors) that caused this effect.

More research in rodents followed, revealing that oxytocin may be a key element not just in caregiver-infant tactile bonding, but also in relationships between peers and partners. Prairie voles, rodents known for being highly social and monogamous, exhibit impairments in social attachment after experiencing maternal separation in the neonatal period. However, administering OXTR agonist alleviated this negative effect of early-life adversity, promoting typical partner preference formation (Barrett et al., 2015). In turn, administering OXTR antagonist to adult prairie voles (who did not experience maternal separation) blocked typical consoling behaviour in the form of licking and grooming toward familiar conspecifics that have experienced a stressor (Burkett et al., 2016). A recent study by Tang et al. (2020) demonstrated that oxytocin neurons in an adult virgin female rat showed an increase in spiking activity during a physical interaction with another female rat, which was especially enhanced when one rat crawled on top of the other (which is a typical affiliative behaviour). No associations between socially-relevant auditory (ultrasonic vocalisations) or olfactory stimuli (urinated-on female bedding) and oxytocin neuron activity was found – meaning that the effect was touch-specific. Moreover, selective inhibition of a subtype of oxytocin neurons led to spending less time with or even avoiding the other rat, while having no effect on general locomotor activity.

Taken together, these studies demonstrate oxytocin's involvement in shaping social behaviours from caregiver-pup bonds to relationships between peers; this research suggests that touch is an important trigger of oxytocin release. Some researchers have even proposed that the touching behaviours exhibited towards peers in adulthood may represent a neurobiological redirection of parental instincts towards adults, which occurs through the oxytocin system regulation (Walum & Young, 2018), thus providing a neurobiological model for phenomena described by attachment theory (Atzil et al., 2011; Bowlby, 1958).

1.3.4.2. Oxytocin and touch – insights from human development research

Rodent research provides an exciting oxytocin-based model for studying the impact of early tactile experiences on development. Yet, it is not clear whether those mechanisms also exist in humans. A lot is known about the associations between human parental oxytocin levels and their caregiving qualities (see Szymanska et al., 2017 for a review), but the infant side of the equation largely remains a mystery. Methods for translating neurodevelopmental findings from rodents to humans (Clancy et al., 2007; Workman et al., 2013) allow for making predictions about those effects in humans, but do not replace empirical evidence collected in studies with human participants – evidence which is currently lacking. One of the reasons for this is perhaps the various challenges associated with measuring oxytocin in humans, especially children. These are discussed in more detail, along with findings coming from research on oxytocin in infants, in Chapter 4.

The fact that caregiver touch might affect oxytocin activity in infants gives rise to the possibility that it would also shape infant social exploratory behaviours, i.e. attention to and processing of social stimuli, in particular – faces. In fact, recently several studies have explored this possibility (Della Longa et al., 2017, 2020; Nava et al., 2020). In Chapters 7 and 8, which are devoted to this specific hypothesis, I review these studies in more detail. Below, I turn to the associations between arousal and non-social exploratory behaviour.

1.4. Touch, arousal and exploratory behaviour

The human stress response system has two main components: the HPA axis, and the autonomic nervous system (Rotenberg & McGrath, 2016; Tsigos & Chrousos, 2002). While the HPA axis is a hormonal system regulating the release of cortisol from the adrenal cortex, the autonomic nervous system is responsible for a range of physiological processes, including the stimulation of the release of noradrenaline from the locus coeruleus, as well as heart rate modulation (Rotenberg & McGrath, 2016). The autonomic nervous system and the HPA axis are physically interconnected, and show a high degree of coordination (Agorastos et al., 2019; Hollocks et al., 2014; Rotenberg & McGrath, 2016). For instance, the neuronal afferents of corticotrophin-releasing hormone from the paraventricular nucleus project to the locus coeruleus, and noradrenergic neurons from the locus coeruleus project to the paraventricular nucleus; cortisol enhances heart rate response to a stressor (Rotenberg & McGrath, 2016). Even though measures of activation of one can indirectly provide information about the activation of the other, they are, in fact, separate systems and the relation between them is not a perfect correlation (Hollocks et al., 2014). Thus, some define arousal as total levels of activity within the autonomic nervous system only (Wass, 2017), while others use the term more generally, as denoting activation within the autonomic nervous system, but also the HPA axis system (Levine et al., 2012; Tsigos & Chrousos, 2002). Given the high level of coordination between the two systems, as well as research showing that touch modulates stress response mediated by both autonomic nervous as well as HPA-axis system, here, I use the more general definition of arousal, but refer to the concrete biomarkers wherever possible.

With evidence that caregiver touch has an effect on various measures of arousal: not just cortisol levels (Feldman, Singer, et al. et al., 2010; Vittner et al., 2017), but also heart rate variability (Aguirre et al., 2019; Fairhurst et al., 2014; Van Puyvelde et al., 2019) and norepinephrine activity (Kuhn et al., 1991), as well as evidence that arousal modulates infant broadly-defined exploratory behaviour (de Barbaro et al., 2016, 2017; Gardner & Karmel, 1995; Geva et al., 1999; Wass & Smith, 2014), it follows that touch could affect exploratory behaviour through modulating infant arousal. This is also consistent with the conclusions coming from animal studies described earlier (e.g. Champagne et al., 2001; Guardini et al., 2017; Simpson, Sclafani et al., 2019). In the following sections, I provide an overview of research on short-term and long-term associations between arousal and exploratory behaviour, in the context of the possible effects of touch.

1.4.1. Arousal and exploratory behaviour – immediate effects

The notion that arousal can affect performance on various tasks is not new. When training mice on an easy brightness discrimination task, Yerkes and Dodson (1908) found that (inferred) increases in arousal caused by an electric shock administered before the mice would perform the task caused a linear improvement in learning: the stronger the electric shock was, the fewer trials the mice needed to learn the discrimination. However, this was only true in case of the most trivial task; when the difficulty of the task was increased by reducing the differences in brightness between the stimuli, not only did the mice require more trials to learn the discriminations, but they also exhibited a curvilinear (inverted-U) relationship between shock intensity and performance (Mair et al., 2011; Yerkes & Dodson, 1908). This discovery led to the conclusion that for all but the easiest tasks, increases in arousal would lead to increases in performance, up to a point of optimal arousal; further increases in arousal beyond that point would lead to decreases in performance (Mair et al., 2011; Yerkes & Dodson, 1908). This relation between arousal and performance is described by what is now commonly referred to as a Yerkes-Dodson law bell curve.

In the decades following the discovery by Yerkes and Dodson (1908), more research on the neurophysiological mechanisms behind the curvilinear relation between arousal and behavioural performance emerged. Possibly the most influential theory building on Yerkes and Dodson's work is the Aston-Jones model of attention (Aston-Jones & Cohen, 2005). The Aston-Jones model links attention during performance of a task with the function of the locus coeruleus-norepinephrine (LC-NE) system – a system of several brainstem neuromodulatory nuclei with widely distributed, ascending projections to the neocortex.

Based on the results of experiments conducted with monkeys, Aston-Jones concluded that there are at least two distinguishable modes in which LC cells operate: the phasic mode, which promotes focused, sustained attention, and the tonic mode, which is associated with high scanning attentiveness (Aston-Jones et al., 1999; Aston-Jones & Cohen, 2005). The relation between LC activity and performance outcomes mirrors the relation between arousal and performance outcomes described by Yerkes and Dodson (1908) in that both follow the inverted-U shape.

The LC-NE system is responsive to ongoing evaluations of the costs and benefits associated with performance provided by input from frontal structures; specifically, from the orbitofrontal cortex, playing a role in the evaluation of reward, and the anterior cingulate cortex, playing a role in the evaluation of cost (Aston-Jones & Cohen, 2005). The two modes of the LC cells serve to optimise the trade-off between exploitation (here understood as focusing on known sources of reward) and exploration (here understood as seeking new sources of reward) (Aston-Jones & Cohen, 2005).

Although the Aston-Jones model focuses on the LC-NE system, its predictions have been confirmed in humans with measures of arousal other than LC cells activity, including electrodermal activity, pupil size and heart-rate derived measures (see Wass, 2017 for a review). This avenue of research with respect to infancy has recently gained more attention in developmental science.

de Barbaro and colleagues (2016) examined the relation between stress reactivity (measured with heart rate) and infant performance on measures of looking duration and visual recognition memory in 12-month-olds. They discovered that those infants who exhibited increased stress reactivity when watching a clip of another child crying, showed shorter look durations in a habituation task (where they were presented with pictures of children smiling, or with neutral facial expressions). These results indicate that increased stress reactivity is associated with more vigilant, stimulus-driven attention profile (de Barbaro et al., 2016). However, while the heart rate-derived measure of stress reactivity was taken in close temporal proximity to the other tasks (all tasks were completed within a 20-minute-long battery of different tasks), it did not provide information about infants' arousal while performing the habituation task.

In a follow-up study, de Barbaro et al. (2017) investigated associations between time-locked measures of arousal and look durations in 12-month-olds. They hypothesised that increases in arousal would dynamically cause shortening of look durations to stimuli presented on a screen.

Indeed, they found that arousal levels (measured with a composite score derived from electrocardiogram, electrodermal activity, peripheral accelerometry, and head velocity data) up to 25 seconds before the onset of the look were predictive of the duration of the look, with the strongest predictive relation at around 20 seconds before the look occurs. What is more, de Barbaro et al. (2017) demonstrated that arousal predicted look durations, but not vice versa. These findings support the Aston-Jones model by showing that periods of heightened arousal (within a typical range) are associated with attentional profile characterised by shorter looks, i.e. more vigilant, bottom-up driven attention.

The studies by de Barbaro et al. (2016, 2017) provide evidence that both stress reactivity unrelated to the task, as well as arousal measured during the task show associations with infant attention during that task in ways that are consistent with the Aston-Jones model predictions. Thus, considering the effects of touch on arousal reviewed earlier, the hypothesis that touch affects infant's exploratory profile is theoretically well-motivated.

1.4.2. Touch, arousal and exploration – immediate effects

To the best of my knowledge, the only work which explicitly investigated the putative immediate effects of touch on attention through modulating arousal, consistent with the predictions of the Aston-Jones model, was the work done by Pirazzoli (2019). Pirazzoli hypothesised that in 6- and 9-month olds, CT-optimal stroking would elicit a decrease in arousal, as measured with heart rate, which, consequently, would lead to longer latencies to reorient to a peripheral stimulus in a visual orienting task. Longer latencies to reorient in the task were assumed to be indicative of intermediate levels of arousal, which favour focused attention (Pirazzoli, 2019); the predicted pattern of results would have been consistent with the idea that affective touch promotes optimal states of arousal for engagement with the environment. However, Pirazzoli did not find support for these hypotheses. While both CT-optimal and CT-nonoptimal (control) stroking stimuli decreased variation in heart rate during the task (i.e., caused a flatter response) compared to a no-touch condition, neither caused a general decrease in arousal (as would be indexed by a decrease in heart rate). Moreover, latencies to reorient to peripheral stimuli, which were the index of focused attention, did not differ between the touch and no-touch conditions.

However, another socially salient cue, eye gaze, has been shown to increase arousal instantaneously, as measured with heart rate, in 9-10-month-olds. These increases in arousal, in turn, predict later gaze following (Ishikawa & Itakura, 2019). It is possible that touch could act in a similar way. This finding is interesting in the context of Della Longa et al. 's (2017) demonstration that social touch applied during the presentation of faces with averted gaze promoted learning of those faces in 4-month-olds, something that they are normally not able to do at this age (Farroni et al., 2007). Although gentle stroking has been shown to have decelerating, rather than accelerating effects on heart rate (Aguirre et al., 2019; Fairhurst et al., 2014, but see Pirazzoli, 2019, for alternative findings), it nevertheless promoted learning in a way that a control stimulus, brush tapping, did not (Della Longa et al., 2017). There are several possible explanations for why this effect occurred (see Chapter 7 for more discussion of this point), but considering the effects of eye gaze demonstrated by Ishikawa & Itakura (2019), it seems that stroking could have somehow mimicked eye gaze effects on arousal as a saliency-enhancing cue in Della Longa et al.'s (2017) study.

Akhtar & Gernsbacher, (2008) argued that the primacy of eye gaze-focused theories of social-cognitive development (and, consequently, the great amount of eye gaze-focused research) stems from a cultural bias, whereby eye gaze is privileged above other cues in Western cultures. It is likely that not only infants in other cultures and atypically developing infants in Western cultures, but also typically developing infants in Western cultures to a large extent rely on non-gaze cues, including touch (Akhtar & Gernsbacher, 2008).

In addition to the immediate effects of caregiver touch on arousal, there is also evidence that caregiver touch could affect infant neurobehavioural stress response long-term.

1.4.3. Long-term effects of touch on arousal and exploration

Stress experienced in infancy, as measured with HPA-axis activity, has consistently been shown to have adverse effects on cognitive development (Blair et al., 2011; Finegood et al., 2017; Suor et al., 2015). Higher levels of salivary cortisol at 7, 15 and 24 months predict lower executive function ability and IQ at age 3 years (Blair et al., 2011). Moreover, Finegood et al. (2017) demonstrated that basal cortisol measured at 7 and 15 months negatively predicted Mental Development Index of the Bayley Scales of Infant Development at 15 months.

Various factors can contribute to stress experienced in infancy; for instance, factors such as maternal age of 19 or less at the time of the first child's birth, and the presence of three or more children in the household have been demonstrated to be associated with elevated basal and reactive cortisol in infants aged 6 and 12 months (Holochwost et al., 2017). Perhaps most robustly, poverty (or, low income-to-needs ratio) has been consistently linked to elevated cortisol levels, or more generally, HPA-axis activity in infancy (e.g. Holochwost et al., 2017; McEwen & McEwen, 2017; Saridjan et al., 2010).

It has been shown that the effects of poverty on HPA-axis activity are mediated by caregiving behaviours, i.e., the experience of poverty affects parental behaviours, which, in turn, affects infant HPA-axis activity (Holochwost et al., 2020; McEwen & McEwen, 2017). Given the effects of tactile stimulation on the HPA-axis function in rodents as well as human infants described earlier, it is very likely that caregiver touch plays a major role in this association. Yet, touching behaviours are rarely explicitly mentioned in the context of the effects of poverty on caregiving behaviours and infant HPA-axis activity[5]. The focus has instead been directed on caregiving qualities such as parental sensitivity, engagement, involvement, warmth and responsiveness (see Holochwost et al., 2020 for a review). These qualities, however, are generally

[5] For instance, in the review article " Poverty, caregiving, and HPA-axis activity in early childhood" by Holochwost et al. (2020) the word "touch" appears only once, and the words "stroking", "holding" or "contact" do not appear at all.

associated with use of affective touch (Botero et al., 2019), and therefore the studies showing associations between poverty, these caregiving qualities, and infant HPA-axis activity indirectly reinforce the notion of caregiver touch being heavily involved in the equation.

In one study, Lyons-Ruth et al. (1990) showed that maternal depression status mediated the effects of poverty on infant developmental status at 18 months, as measured with the Bayley Mental Scale: infants of depressed mothers scored 10 points less on average than infants of mothers who were not depressed (Lyons-Ruth et al., 1990). Maternal depression is associated with decreased use of affective touch (Herrera et al., 2004; Mantis et al., 2019). Moreover, maternal self-reported stroking was shown to have a protective effect against some of the adverse effects of maternal depression on child emotionality (which I discuss in more detail further on in the current chapter; Pickles et al., 2017; Sharp et al., 2015; Sharp et al., 2012), which makes it even more likely that touch plays a critical role in the connection between environment quality and infant development.

However, the fact remains that caregiver touch in itself has not been explicitly acknowledged as a potentially vital factor in the transmission of environmental effects on infant arousal regulation in the context of early adversity, despite strong premises to do so. The notion that touch should be more explicitly incorporated in infant development research has recently been put forward by Botero (2018) and Botero et al. (2019). Although capturing this means of interaction is notably challenging, caregiver touch is (quite literally) a more palpable quality than caregiver sensitivity, engagement or involvement. I would argue that shifting the focus from abstract concepts like maternal sensitivity to more concrete, observable behaviours, particularly – touching, would also be beneficial in the light of the scientific quality criterion of parsimony. This is not to say that concepts such as parental sensitivity are not useful, as it is the case that parents will intuitively comfort their infants by means of a multimodal package that combines a variety of regulation aspects (Van Puyvelde et al., 2019); understanding what drives the variation in multimodal caregiving behaviours is certainly important. However, by looking at concrete, observable behaviours, it is possible to better quantify and characterise the mechanisms behind the investigated effects.

Consistent with the idea that infants adapt to their environments, rather than simply being impaired by early adversity, Chaby et al. (2015a 2015b) proposed that early stress may modulate the relation between arousal and performance in a way that actually enhances performance under high stress conditions for those who had experienced high levels of early stress. Studying the behaviour of rats raised in different environments, they observed that under low-threat conditions, those rats who were exposed to more stress in development took longer to visit a novel location in a foraging test, and visited fewer patches with food than the control group did (Chaby et al., 2015b). Conversely, under high-threat conditions (addition of brighter lighting and predation cues to the foraging area), the animals raised under high-stress conditions performed better than the ones in control group, approaching novel locations faster, and visiting more food patches. This observation led to forming an "arousal-shift" hypothesis, whereby an individual's curve representing the classic Yerkes-Dodson relation between arousal and performance is shifted along the arousal axis, depending on the early stress they experienced (see Figure 1.3).

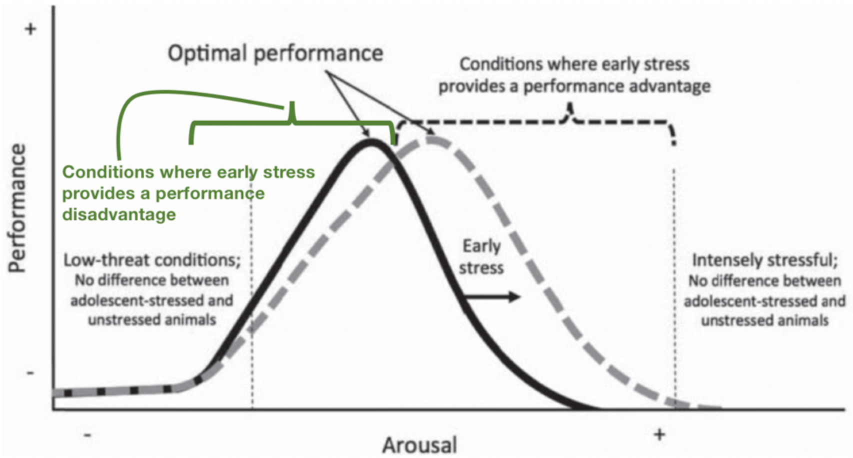

Figure 1.3. An illustration of the "arousal-shift" hypothesis describing the effects of early stress on the relation between arousal and performance. The marker and comment in green added by myself; adapted from Chaby et al. (2015)

1.4.4. HPA-axis activity and neurocognitive development in infancy

Finegood et al. (2017) demonstrated a predictive negative relation between infant cortisol at 7 and 15 months and Mental Development Index (MDI) from the Bayley Scale of Infant Development, which is also one of the developmental indices that Kangaroo Care had a positive effect on at 6, 12, and 24 months (Feldman et al., 2014). There is very possibly a causal relation there, with Kangaroo Care having an effect on infant HPA-axis activity, as measured with salivary cortisol, and infant HPA-axis activity modulating infant cognitive development, as measured with the MDI index.

The relation between infant HPA-axis activity and cognitive development has recently gained more attention but the mechanisms behind this relation are not completely clear (Finegood et al., 2017). However, in adults, it has been shown that chronic stress is associated with hypertrophy and overactivity in the amygdala and orbitofrontal cortex, as well as loss of neurons and neural connections in the hippocampus and medial prefrontal cortex (PFC) (McEwen & Gianaros, 2011; Shonkoff et al., 2012). The functional consequences of these structural changes, as described by McEwen & Gianaros (2011) and Shonkoff et al. (2012), include more anxiety, related to both hyperactivation of the amygdala, and less top-down control, as a result of PFC atrophy, as well as impaired memory. These changes are consistent with an exploratory profile prone to avoid novelty (or, decreased approach of novelty), and bottom-up-driven attention – more vigilant scanning of the environment characterised by shorter looks.

1.4.5. Caregiver touch, infant stress response activity and exploratory behaviour

Building on the research described above, I propose that a way in which touch and, consequently, stress response, could affect cognitive development, is through modulating infant exploratory behaviour (i.e., the ways in which the infant engages with their environment).

Experiencing more stress early on would lead to a profile prioritising familiarity over novelty (or, exploitation over exploration); moreover, it would lead to more vigilant, or bottom-up-driven (vs. sustained) attention. Such pattern of information sampling is beneficial in an unpredictable, hostile environment; however, in safe environments full of resources, it could lead to adverse cognitive outcomes in the long term. Conversely, experiencing more touch in infancy would lead to less experienced stress, and more preference for novelty over familiarity, as well as promote the ability to focus attention on an object of interest, without the need to continuously monitor the environment for possible dangers.

In light of some researchers (Holochwost et al., 2020; McLoyd, 1998; Meaney, 2001) suggesting that the effects of adverse environments on child development are almost exclusively mediated by caregiver behaviours, and following the hypothesis that touch is a particularly strong cue of environment quality, it seems that caregiver touch could affect infant HPA-axis activity and exploratory behaviour regardless of whether the environment is "objectively" difficult (e.g. as indexed by income-to-needs ratio, maternal age etc.). Arguably, something like maternal depression, which reduces touch, could also be considered part of the infant's environment; the boundaries between what constitutes the environment and what constitutes caregiving qualities are somewhat blurred. Here, following others (Holochwost et al., 2020; McLoyd, 1998; Meaney, 2001), I propose that caregiver behaviours in terms of the amount of touch employed with the infant (but also face-to-face interactions, speech etc. – any behaviours that the infants can experience, as opposed to unobservable qualities, like the diagnosis/experience of depression by their mother) are what "translates" environmental qualities (often labelled as general developmental risk-factors by researchers) to the infant. In this light, for example, maternal depression is a part of the infant's environment, and altered maternal behaviours associated with depression, including – but not limited to – reduced use of touch (which are not necessarily specific to maternal depression) signal this adversity to the infant.

Caregivers exhibit a considerable amount of individual differences in how much touch they employ when interacting with their infants (e.g. Jean et al., 2009; Mantis et al., 2019). Consistent with the accounts of caregiver-mediated effects of environment quality on the infant, these individual differences would largely be driven by the circumstances the caregivers find themselves in. For instance, a parent struggling to make ends meet may simply be too busy or too tired to often engage in touching interactions with their child (this would, in fact, most likely be true not just with regard to touching interactions, but interactions in any type of modality). However, there is undoubtedly also a significant proportion of individual variation in the use of caregiver touch explained by factors other than environment quality. For instance, in rodents, the amount of licking and grooming the mother provides to her offspring is trans-generationally modulated by the amount of licking and grooming she herself received in infancy, independently of the environment conditions she was raised in (Francis et al., 1999). In humans, attitudes and affects associated with social (not just caregiving) touch differ between socially low-anxious and high-anxious people (Wilhelm et al., 2001). These are just some examples of what is likely a myriad of factors possibly affecting the use of caregiver touch.

This is just to say that although much of the reviewed research was concerned with rather extreme experiences of environment adversity, it is plausible that naturally occurring variation in caregiver touch could shape infant arousal regulation and, in consequence, exploratory behaviour and cognitive development regardless of environmental circumstances.

It has to be noted that there are significant differences between cultures in the amounts and types of touch used with infants (Akhtar & Gernsbacher, 2008; Little et al., 2019). Given the countries where the research for this thesis was conducted, Germany and England, as well as my own cultural biases, most of the perspectives presented here are culturally Western-focused[6]. It is characteristic of Western parents that, on average, they favour visual modality over touch when

[6] Although it has to be noted that both the Frankfurt am Main area and London (from which our participants are drawn) are both culturally diverse places.

interacting with their infants, and generally employ less touch than parents from many other cultures (Akhtar & Gernsbacher, 2008). Returning to the hypothesis about the crucial role of touch in healthy development, would this mean that infants raised in Western cultures were developmentally disadvantaged because of their parents' cultural practices? Some have indeed speculated that this relatively sparse use of touch might be a reason why mental health problems appear to be more prevalent and severe in the Western world (Vetulani, 2013). Even differences in behaviours between pre-schoolers from different Western countries have been attributed to the different amounts of touch provided by their parents; for example, Field (1999) observed that American children were more aggressive than French children, which she argued was a consequence of being touched less by their parents. Following the implications of animal research, I favour the hypothesis that it is the absolute amounts of touch that infants receive that matter for their development. In so doing, I recognise that there are possible cross-cultural implications of this hypothesis, but these are beyond the scope of the current thesis.

1.5. An alternative hypothesis: touch as an intersensorily redundant cue

Beyond the touch – arousal – exploration – learning model, there is also a modest body of research devoted to effects of touch on learning happening through intersensory redundancy (e.g. Abu-Zhaya et al., 2017; Lew-Williams et al., 2019). For instance, in a series of experiments, Lew-Williams et al. (2019) demonstrated that touching patterns congruent with an audio stimulus (e.g. knee-elbow-knee touch accompanying an A-B-A sine-wave tone) facilitated learning of the auditory patterns in 7-month-olds, while incongruent touching patterns (e.g. knee-knee-elbow touch accompanying an A-B-A sine-wave tone) did not produce such effects. Given the dependency of the effect on the congruency between patterns of touch and sound, this finding indicates that enhanced learning did not occur through non-specific saliency enhancing effects of touch on arousal. Therefore, the authors of the study interpreted this result in the context of the intersensory redundancy hypothesis (Bahrick & Lickliter, 2014), according to which events which are intersensorily redundant 'pop out' for the infant, and thereby draw the infant's attention to perceptually salient information (Bahrick & Lickliter, 2014; Lew-Williams et al., 2019).

Consistent with this interpretation, it may seem that there is nothing "special" about the tactile modality and the effect could have been achieved through providing redundancy in another (e.g. visual) modality. Nonetheless, Lew-Williams et al. (2019) point out that touch in itself is redundant across senses (i.e., the person being touched can often see, and perhaps even hear the touch), and particularly in infancy, touch tends to co-occur with input in other modalities (Frith & Frith, 2007). Moreover, when asked to read a book to their 5-month-olds, mothers have been shown to spontaneously employ touch during book-reading in a way where touch events mostly co-occur with speech, and depend on the content of the books (e.g. more touches when the book was on body parts; Abu-Zhaya et al., 2017). This finding further supports the notion that touch may be spontaneously used by caregivers to support infant learning, through providing intersensorily redundant information.

Abu-Zhaya et al. (2017) also found that there was substantial individual variation in the frequency of use of touch during mother-infant book-reading interactions. This raises an interesting question of what was the driver of these individual differences. It seems highly plausible that caregivers who generally tend to use more touch with their infants, would also do so during book-reading (and other learning) interactions, thus supporting their learning through the means of intersensory redundancy. This effect would likely be dependent on parents' ability to coordinate touching patterns with stimuli in other modalities. Although this thesis does not specifically focus on the intersensory redundancy account of touch-learning effects, nevertheless the predictions of this account are consistent with the idea that more use of (congruent) caregiver touch would promote learning in infancy, albeit through a different mechanism than through modulation of arousal.

Returning to the original hypothesis about touch acting as a signal of environment quality, an important question that remains is: what types of caregiver touch are particularly consequential for infant arousal and exploratory behaviour?

1.6. Types of touch and their effects on arousal and exploration

In rodents, it was the natural variation in maternal licking and grooming behaviours towards the pups that affected the physiological and behavioural expressions of fearfulness (Caldji et al., 1998; Champagne & Meaney, 2007; Liu et al., 1997). Naturally, these are no typical caregiving behaviours in humans. In an animal more akin to the human, the macaque monkey, it was holding and swaddling that promoted more positive response to novelty (Simpson, Sclafani, et al., 2019). What type of touching behaviour could cause similar effects in humans?

The repertoire of touching behaviours in human caregivers is broad, with researchers having chosen to include four (Feldman, Gordon, et al., 2010), six (Mantis & Stack, 2018) or even nine (Jean et al., 2009) different types of caregiving touch in their observational coding schemes. The coding schemes based on low-level, descriptive properties of touch (e.g. static touch, stroking etc.; Jean et al., 2009) tend to differentiate between more categories of touch than the schemes focusing on the functions of touch (e.g. affective touch, stimulatory touch etc.; Feldman et al., 2010). However, in recent years one particular type of tactile stimulation has received intensive attention from the researchers; namely, stroking (e.g. Pirazzoli et al., 2018; Sailer & Ackerley, 2017; Van Puyvelde et al., 2019; Walker et al., 2017).

1.6.1. Stroking

Stroking was found to uniquely activate a specific type of unmyelinated mechanoreceptors in the skin, the C-tactile afferents (Vallbo et al., 1999); their activation was shown to correlate with perceived pleasantness of touch in adults (Löken et al., 2009). Interestingly, the stroking velocities C-tactile afferents respond most strongly to (between 1 and 10 cm/s)[7] are spontaneously applied in interpersonal interactions, including those between parents and their babies (Bytomski et al., 2020; Croy et al., 2016; Löken et al., 2009; see Figure 1.4). In 9-month-old infants, stroking at C-tactile-optimal velocity (but not at higher or lower velocities) caused a significant decrease in heart rate, indicating a decrease in arousal (Fairhurst et al., 2014). A later study showed however that for this effect to occur, the infant has to believe that the tactile stimulation is delivered by their caregiver (or someone familiar; Aguirre et al., 2019).

Given these characteristics of stroking, researchers have turned their attention to this type of tactile stimulation as potentially playing a special role in development. Sharp et al. (2012) showed that maternal (self-reported) stroking in the first weeks of infant life had a protective effect against adverse consequences of maternal prenatal depression. In the presence of high maternal stroking, increasing maternal depression was no longer associated with infant's decreasing vagal withdrawal, an electrocardiogram-derived measure the authors used as an index of "*an individual's capacity to regulate cognitive and emotional processes and therefore respond effectively to a challenge*"[8] (Sharp et al., 2012, p. 1). Perhaps surprisingly, there was no direct correlation between maternal stroking and infant vagal withdrawal (Sharp et al., 2012), or, in the following studies with the same cohort, children's internalising and externalising symptoms at 2.5 years (Sharp et al., 2015) and 3.5 years (Pickles et

[7] However, these velocities were calculated in adult humans; it is possible that the optimal velocities might be defined in body-scaled units, rather than in absolute values, in which case the CT-optimal velocities in infants would be slower than in adults.

[8] It has to be noted that the authors only cite one paper (El-Sheikh et al., 2001) providing evidence for vagal withdrawal correlating with beneficial outcomes in terms of emotional development in 8 to 12 year old children, so their interpretation of the measure has to be treated with caution.

al., 2017); in these studies, stroking was only found to moderate the associations between maternal depression and child outcomes in ways suggesting its protective, rather than direct role in shaping child emotional development.

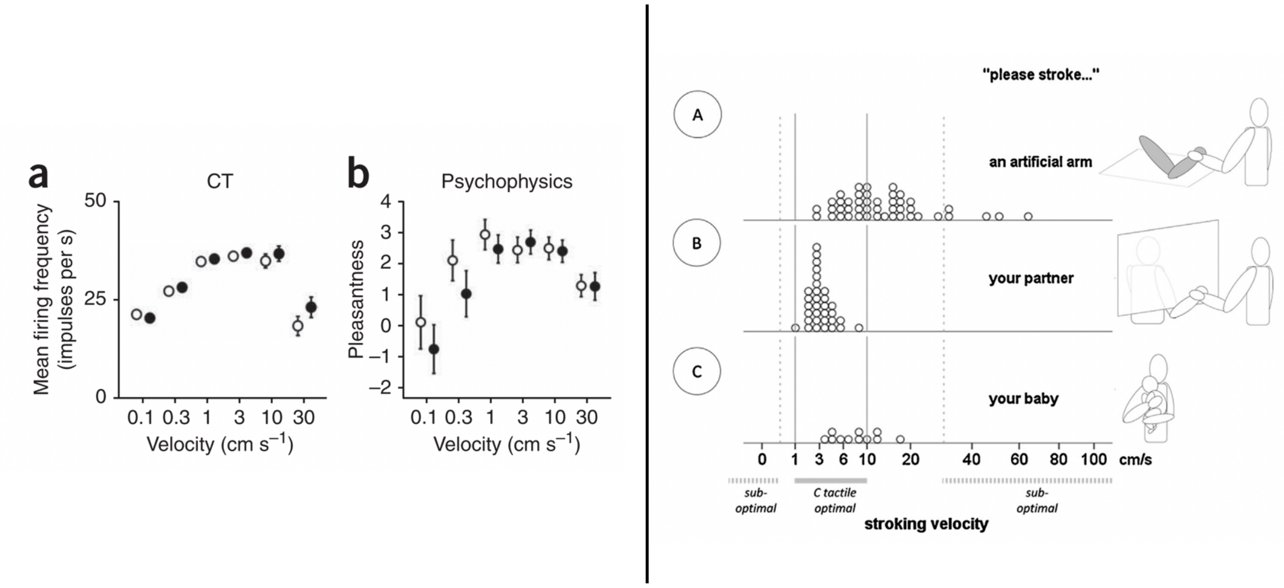

Figure 1.4. Left: C-tactile neural discharge rate (a) and perception of pleasantness (b) as a function of stroking velocity; figure taken from Löken et al. (2009). Right: distributions of stroking velocities used when participants were stroking an artificial arm (A), their partner (B) and their baby (C); figure taken from Croy et al. (2016).

However, in a recent experiment, Van Puyvelde et al. (2019) demonstrated a direct effect of stroking on a measure closely related with vagal withdrawal, respiratory sinus arrhythmia, in 1- to 4-month-olds. Consistent with the findings of Fairhurst et al. (2014) and Aguirre et al. (2019), this finding supports the notion of immediate effects of touch on infant arousal. Nonetheless, it is yet to be established if naturally occurring variation in caregiver stroking has lasting consequences on infant arousal regulation under typical circumstances.

Much of the research focus around caregiver stroking has concentrated on its effects on infant arousal and emotion regulation (Aguirre et al., 2019; Fairhurst et al., 2014; Pickles et al., 2017; Sharp et al., 2015; Sharp et al., 2012; Van Puyvelde et al., 2019), which only partly addresses the scope of rodent research implications (Champagne & Meaney, 2007). To date, only one published study has directly investigated the relation between stroking and learning in infancy, showing that stroking improved learning of face identities in 4-month-olds (more on that in Chapter 7; Della Longa et al., 2017).

While C-tactile-targeted stroking has been the main focus of research on caregiver touch, there are good reasons to suspect that other types of affective touch may be just as important in development. The specificity of some of the discovered effects was not always apparent. For instance, the studies on the protective effects of stroking against adverse consequences of maternal depression (Pickles et al., 2017; Sharp et al., 2015; Sharp et al., 2012) all used the Stroking subscale of the PICTS measure, which highly correlates with the other two subscales: Holding and Affective Communication (Koukounari et al., 2015).

What is more, even though the abovementioned studies focused on particular touch types, the experimental studies, measuring immediate effects of stroking on arousal, have often used C-tactile non-optimal stroking velocities (below or above 1 – 10 cm/s) as a control condition (Aguirre et al., 2019; Fairhurst et al., 2014). This type of control condition is strongly motivated by research on C-tactile afferents (Löken et al., 2009), and is useful when the research hypotheses pertain to C-tactile-mediated effects. Nevertheless it does not allow for comparisons between C-tactile-optimal stroking and other types of naturally occurring social touch, as non-optimal stroking velocities are not spontaneously employed in interpersonal interactions (see Figure 1.4., Croy et al., 2016), and thus may not be a naturalistic tactile stimulus. Perhaps, for example, passive touch or tapping would be a more appropriate control stimulus, if the hypotheses pertain to the effects of stroking relative to other naturally occurring types of interpersonal touch.

Further supporting the notion that some of the reported effects of C-tactile-targeted stroking in infancy may not be specific to this type of stimulation, Pirazzoli (2019) recently demonstrated that both on the level of cortical processing of tactile stimuli, as well as on the level of heart rate response, by the age of 9 months, infants do not yet differentiate between C-tactile-optimal and non-optimal touch. Not only did Pirazzoli (2019) fail to replicate the results of Fairhurst et al. (2014), but she also extended the scope of her investigations to the putative effects of C-tactile stroking on attention, which she also did not confirm.

Additional relevant evidence comes from studies on non-mammal animals. Stress-buffering effects of touch have in fact been observed in fish (Schirmer et al., 2013; Soares et al., 2011), and therefore it is unlikely that the effects of touch on arousal are (exclusively) C-tactile-mediated, as C-tactile afferents are only present in the skin of mammals (Olausson et al., 2002). While it is evident that C-tactile afferents play a unique role in processing tactile stimuli, their function might be more specialised and pertain to social-communicative functions of touch.

For instance, in adults, the experience of being stroked on the arm (which is densely CT innervated) enhanced processing of social vocal sounds, as indicated by event-related potentials, in comparison with being stroked on the palm (negligible CT innervation) and not being touched at all (Schirmer & Gunter, 2017). Moreover, this effect was most pronounced for surprised vocal relative to neutral vocal and non-social sounds, indicating a specific effect of CT-targeted touch on processing of highly socially relevant information.

1.6.2. Deep pressure, and the quantity over quality hypothesis

However, recently Case et al. (2020) put forward a hypothesis that many of the functions originally thought to be specific to CT-targeted touch actually pertain to other forms of tactile stimulation, in particular – touch involving deep pressure. This type of tactile stimulation occurs not only in massages, known to have far-reaching therapeutic effects across development (e.g. Diego et al., 2004; Listing et al., 2010; Morhenn et al., 2012), but also in everyday interactions such as hugging and cuddling (Case et al., 2020).

The hypothesis of Case et al.'s (2020) is particularly interesting in the context of infant caregiving, where holding and cuddling behaviours occur much more often than stroking (Jean et al., 2009). Indeed, there is evidence that cortical specialization to stroking, observed in adults, might not develop until the end of first year of life, which undermines the claims about the special role of stroking in infancy (Pirazzoli, 2019; Pirazzoli et al., 2018). Based on a series of studies which did not confirm many of the hypothesised effects of stroking on heart rate and brain activity, Pirazzoli (2019) concluded that the role of stroking in affective touch research might indeed be overestimated, and more focus should be directed at less active forms of touch, such as holding and cuddling.

Recently, Field (2019) pointed out that although there seems to be a degree of disconnection between research on touch in parent-child interactions, CT-targeted touch, and massage therapy, findings from these fields all point towards beneficial effects of touch on development and well-being. Thus, a more integrated account of affective touch in which stroking, but also body contact and deep pressure tactile stimulation are given attention is needed, especially in the context of infant development.

Moreover, if we accept that caregiver touch signals the quality of the environment in which the infant develops (as suggested by Meaney's hypotheses discussed above), perhaps the quantity of caregiver touch is more important than the quality of caregiver touch. If touch indicates the availability of the caregiver, then it is possible that more parental touch of any species-specific kind (other than, of course, nociceptive and otherwise harmful touch) would convey the sense of safety, and elicit a drive to explore. It is also possible that whether quantity or quality of touch matters depends on age.

1.7. When does caregiver touch shape infant exploratory behaviour?

Another important question regarding the effects of caregiver touch on infant development pertains to when in development caregiver touch has most impact. Kaffman & Meaney (2007) proposed that the well-established fact that exposure to visual and auditory stimulation particularly in the neonatal period has far-reaching effects on neurocognitive development which last until adulthood (Bao et al., 2003; Wiesel & Hubel, 1963) is likely true about the sense of touch as well. In rodents, it was shown that tactile stimulation provided in the first three weeks of life has the most profound impact on offspring's development (Kaffman & Meaney, 2007; Meaney, 2001; Smotherman, 1983). Much of the research with macaque monkeys focused on the neonatal period as well (Simpson, Maylott, et al., 2019; Simpson, Sclafani, et al., 2019). Although in some studies macaques receiving different caregiving experiences were followed longitudinally for up to a couple of years (Maestripieri et al., 2006, 2007), the manipulation of tactile caregiving was introduced shortly after birth. Thus, while there is much evidence that in non-human primates it is the neonatal period when tactile experiences have major consequences on neurocognitive development, it is not evident that these effects of touch are limited to, or most pronounced, in this period alone.

Although the timing of neurodevelopmental events and, in particular, sensitive periods in development is not easily translatable between species (Workman et al., 2013), it is likely that in humans, touch provided in the neonatal period is especially impactful as well. In case of infants born prematurely, it was touch-based interventions implemented in the first weeks after birth that were found to have lasting beneficial consequences on their development (Feldman et al., 2014). However, it is important to understand if caregiver touch experienced later in infancy, and by infants born at term, can affect neurocognitive development in a significant way as well. In particular with regard to exploratory behaviour, it may be the case that touch experienced during the time when active exploratory skills are developing most intensively would have substantial impact on this domain.

As noted by Adolph & Hoch (2019), as infants develop, they engage in more, and more costly, means of exploration. From mainly absorbing information about their surroundings through vision, they move to ways of information sampling which require more effort, including reaching for, fingering, banging and shaking objects (Adolph & Hoch, 2019; Fontenelle et al., 2007). As the means of exploration get more complex, they also get more risky. For instance, infants who have mastered reaching skills are now faced with decisions about whether or not to reach for novel objects they encounter – doing it could potentially result in harm. If they had been receiving high levels of parental touch from birth, signalling to them that the environment they are growing up in is safe and of high quality, they may be more likely to actively engage with novelty. However, it may also be the case that touch received especially during the time when more means of exploration are becoming available to the infant would have a significant impact on promoting exploration.

With a multimodal package of ways a caregiver can signal their availability to their child, and thus the safety of the environment, touch may be particularly successful at communicating caregiver proximity to the infant while promoting independent exploration at the same time. Auditory cues may be ambiguous as to the proximity of the caregiver; visual cues require the infant to divide their attention between the caregiver and the object they are exploring. Although such periods of triadic (infant-other-object) exchanges are in fact crucial in neurocognitive development, particularly the development of communicative skills (Grossmann & Johnson, 2007; Trevarthen, 1979), they require effortful engagement from the caregiver's side. Touch – holding, stroking, passively keeping a hand on the infant's body – can often be done while the caregiver is involved in another activity. It also allows infant's attention to be maintained on the object they are exploring, while feeling the caregivers proximate presence, thus potentially promoting independent exploration – both in terms of novelty approach, as well as sustained attention.

Therefore, I hypothesise that at around 5 - 6 months, when active motor exploration involving holding, fingering, and throwing, among other actions, rapidly develops (Lobo et al., 2015), is when caregiver touch could be particularly impactful in shaping infant exploratory skills. While caregiver touch received throughout development, starting from birth, would continue to shape infant neurobehavioural stress response, touch received during this period could specifically promote active engagement with the environment.

Moreover, the processing of touch depends on one's body representation (Longo et al., 2010; Tamè et al., 2019). Even though some have posited that the ability to perceive the bodily self is well specified from birth (Rochat, 2010), it is after 6 months of age when infants' perceptions of tactile stimuli become independent of the position of their body (Bremner & Spence, 2017; Bremner et al., 2008; Rigato et al., 2014). Therefore, as an infant's body representation matures, their experience of touch changes as well. It is possible that how infants experience caregiver touch as a signal of caregiver availability would be somewhat affected by how accurately they perceive tactile stimuli; in particular, correctly identifying the source of touch as the caregiver could be an important factor in whether or not the infant experiences touch as signalling safety. Even more significantly, the ability to accurately represent touch spatially seems like a necessary criterion for touch facilitating learning in the context of the intersensory redundancy hypothesis described earlier (Lew-Williams et al., 2019).

Thus, I argue that despite the enhanced focus on the neonatal period, caregiver touch may continue to profoundly impact infant development, particularly with regard to exploratory behaviour, well beyond the first weeks of life. Even if there is nothing "special" about the effects of caregiver touch received during the time manual exploratory behaviour rapidly develops, at the very least, it is worthwhile to study the associations between caregiver touch and infant exploratory behaviour beyond the sixth month of life, when the latter undergoes the most intense development, with more risky modes of exploration becoming available to the infant (Adolph &

Hoch, 2019); this is when infant novelty approach and sustained attention become better measurable.

It is possible that further in development, as infants develop their gross motor skills and become more mobile, the role of caregiver touch would decrease (Gliga et al., 2019). Yet, this could also the time when we would be able to observe more variability in caregiver touching behaviours. As infants would rely less and less on being held and carried around, factors other than infant dependence on caregiver proximity could become more significant drivers of caregiver touch (although increased mobility is also associated with increased risk of harm and thus potentially even more reliance on caregiver cues). Thus, caregiver touch may continue to shape infant exploratory behaviour well beyond the first year of life. In fact, there is evidence that stress-buffering effects of parental touch are still evident in childhood, and only become weaker in adolescence – both in terms of behavioural (Brummelman et al., 2018) and physiological (Hostinar et al., 2015) indicators of stress.

1.8. Extreme experiences vs. typically occurring variation

If it is the amount of touch rather than the type of tactile stimulation that matters most in development, then it is important to establish the degrees of deviation in the amount of parental touch which are consequential for infant development. Much of the seminal research suggesting the importance of touch in early life was focused on rather extreme tactile experiences. Studies on infants in institutionalised care (most famously, infants raised in Romanian orphanages, known for their severe conditions[9]) showed that neglect and deprivation of adequate caregiving has lasting

[9] The conditions in Romanian orphanages were largely caused by the policies introduced by Nicolae Ceaușescu in 1960s, which heavily restricted access to abortion and contraception; forced births resulted in many parents not being able to afford looking after their children, and the children ending up living in overcrowded orphanages. Moreover, a large number of Romanian women lost their lives due to illegal, dangerous abortions (Jeanblanc, 1990).

consequences on intellectual, physical, behavioural, and social–emotional domains of development that often persist until adulthood (Beckett et al., 2006; Maclean, 2003). However, the experiences of infants in institutionalised care are atypical, and rather extreme.

More insights into the role of touch in development come from studies showing beneficial effects of touch-based interventions in the form of Kangaroo Care (Cong, Ludington-Hoe, & Walsh, 2011; Feldman, Eidelman, Sirota, & Weller, 2002) and massage (Field, Diego, Hernandez-Reif, Deeds, & Figuereido, 2006; Gitau et al., 2002). While these studies were extremely valuable in showing a direct, causal link between touch-based interventions and infant developmental outcomes, they almost exclusively featured infants born prematurely. Therefore, while these studies reinforce the idea that touch enrichment has therapeutic benefits in medical contexts, the results cannot be generalised to infants born at term, or touching behaviours spontaneously employed in caregiving interactions with infants.

It is indeed important to understand whether naturally occurring variations in everyday caregiver touch are consequential for development in the general infant population, as has been found in animal work (Gliga et al., 2019). The studies done with rodents (Caldji et al., 2004; Champagne et al., 2001; Kaffman & Meaney, 2007; Liu et al., 2000) focused on tactile stimulation spontaneously employed by mothers with their pups, showing that not only were there developmental differences between pups receiving higher and lower levels of touch, but the relation between licking and grooming and infant outcomes, particularly measures of exploratory behaviour, was linear (Caldji et al., 1998).

These findings suggest that it is not just experiences on the extreme ends of the caregiver touch spectrum, tactile deprivation and tactile enrichment in the form of touch-based interventions, which are associated with effects on infant outcomes, but differences in the amounts of caregiver touch within a typical range could impact infant development as well. Translating this in the context of human caregiving, it would not just be parents neglecting their infants, or parents regularly providing baby massages who would alter infant development with their touch-related behaviours (negatively in the former, and positively in the latter case), but differences in terms of hormonal response, exploratory behaviour and social orienting and cognition should also be observed between infants receiving, for instance, cuddles less and more often (although those differences would be less pronounced than in the former example). This hypothesis finds some support in the fact that that poor parental bonding not considered abuse or neglect is also associated with increased distress experienced in adolescence, and general worse well-being (Canetti et al., 1997; Kaffman & Meaney, 2007), indicating that differences in caregiving which are not deemed extreme might still have substantial consequences on development.

Knowing that alterations in the quantity of everyday touch are consequential for infant development could be particularly helpful when communicating with parents: a scientifically-motivated encouragement to hug, cuddle with, stroke and kiss their babies more often might potentially be met with a more positive response than advice to sign up for baby massage classes, or to perform everyday one-hour-long sessions of Kangaroo Care. A systematic review of barriers associated with implementing Kangaroo Care indeed found that concerns about time and effort, as well as access to appropriate training have prevented many parents globally from practicing Kangaroo Care with their infants (Chan et al., 2016).

In fact, the structured formula of the Kangaroo Care intervention, both in terms of timing duration and schedule, as well as the form of touch, might have been, to an extent, more motivated by the experimental need for well-controlled and precisely defined intervention, rather than actual premises about specific effects of the chosen parameters of the intervention. Even though when it was originally introduced in 1978, Kangaroo Care was supposed to mimic the function of incubators, the form of Kangaroo Care was actually inspired by spontaneous maternal behaviours – mothers hold babies to their chest instinctively (Campbell-Yeo et al., 2015). The fact that the effects of 1-hour-long sessions performed daily for 14 consecutive days on child neurocognitive development were found to be robust (Feldman et al., 2014) might also mean that similar effects could be observed if parents altered their behaviours by increasing the amount of time spent in body contact with their infants; however, this is yet to be confirmed, particularly with regard to infants born at term.

1.9. Main goals and outline of the thesis

In the current thesis, I focus specifically on **naturally occurring** variation in caregiver touch, and its effects on **social and non-social exploratory behaviour** in infants **born at term**. In particular, I focused attention on infants old enough to engage in active forms of manual exploration (6 – 8 months), as well as infants not only able to do that, but also capable of a degree of gross motor independence from their caregivers (11 – 13 months), in order not just to investigate the link between caregiver touch and infant exploratory behaviour, but also to test if this link is affected by infant gross motor development status (as approximated by their age).

A large body of animal research has shown that tactile stimulation affects how animals behave in novel environments and react to novel objects, with higher levels of received touch promoting a more positive response to and more engagement with novelty. These effects seemed to have been mediated by arousal. Moreover, links between tactile stimulation and oxytocin levels, a hormone heavily involved in social behaviours, have been demonstrated. Lately, evidence has been emerging that in human infants, touch might particularly affect response to social stimuli, promoting social learning.

Based on the reviewed research, in the current thesis I focus on two overarching putative mechanisms through which caregiver touch might affect infant exploratory behaviour. The first one pertains to the effects of caregiver touch on arousal, and, in turn, general information sampling strategies. I hypothesise that in novel and potentially stressful situations, more caregiver touch would be associated with lower arousal. Lower arousal, in turn, would promote more approach of novelty, and better sustained attention when engaging with novelty. Moreover, caregiver touch could shape infant stress response long term, and, consequently, promote exploratory behaviour.

The second putative mechanism concerns possible effects of touch on social attention. I hypothesise that caregiver touch would modulate – overt (looking patterns) or covert (emotional response and focused processing) – attention to social stimuli. These hypothesised mechanisms are pictured in Figure 1.5., which summarises the theoretical model this thesis is based on.

Despite strong premises to do so, the topic of the effects of naturally occurring variation in caregiver touch on infant non-social and social exploration has remained largely understudied. There are several ways in which I aim to contribute to filling this gap with the present thesis.

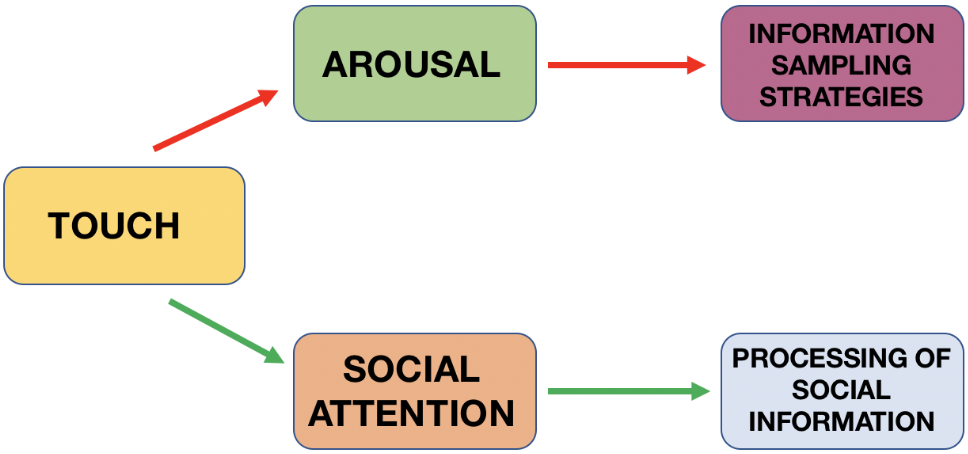

Figure 1.5. Hypothesised mechanisms behind the putative touch – exploratory behaviour effects.

Firstly, I argue that a major reason why this topic remains understudied is the challenge of capturing touch in parent-infant interactions. Methods employed in animal research are not feasible in human infancy research; approaches that have been employed in human infancy research have, to a large extent, focused on touch-based interventions such as Kangaroo Care and baby massage. In Chapter 3, I present an overview of the various measures which have been used to capture naturally occurring variation in caregiver touch, in particular parent-reports (one-off questionnaires and diary) and observation-based methods, along with my own investigation into whether these measures capture similar or divergent qualities of touch.

In Chapter 4, I describe an investigation into the associations between caregiver touch and infant hormonal response. I focus on two hormones which might mediate the effects of touch on infant exploratory behaviour: oxytocin, which is thought to be involved in social attention, and cortisol, a measure of arousal, possibly involved in regulating infant information sampling strategies.

In Chapter 5, I write about information sampling strategies which I hypothesise are regulated by caregiver touch, through its effects on arousal: novelty approach and sustained attention. Before investigating the effects of touch and arousal on these dimensions of exploratory behaviour, it is important to better understand these dimensions themselves. Most animal research on the effects of touch has employed measures of exploratory behaviour taken when the animals were engaging with real-life objects and environments, but in infancy research, there is a great popularity of eye-tracking-derived measures of information sampling strategies. Thus, looking at both manual and visual exploration, I present an investigation into whether seemingly analogous measures of novelty approach and sustained attention can actually be considered equivalent.

In Chapter 6, integrating the findings from the previous chapters, I test the hypothesis that caregiver touch is associated with more approach of novelty, and better sustained attention, which, in turn, can both be predicted by infant arousal.

In Chapter 7, I specifically focus on the putative effects of caregiver touch on overt measures of infant social attention. I attempt to answer the questions: does more caregiver touch in infants predict enhanced attention to social, relative to non-social stimuli? Is infant overt social attention predicted by oxytocin levels?

Finally, in Chapter 8, I introduce a small study on neural correlates of infant attention to social stimuli – faces. Evidence exists that touch increases a positive affective response to faces, and might also enhance infant processing of faces. I examine whether the amount of everyday caregiver touch is associated with infant emotional response and focused attention, as assessed with covert measures derived from infant electrical brain activity, to familiar and unfamiliar faces expressing different emotions.

Lastly, I have to address the impact that the COVID-19 pandemic had on my research. I initially planned to conduct a large, correlational study across a broad age range, incorporating many variables, which would then be followed-up by a set of experiments testing a much narrowed-down set of hypotheses. I managed to do the former, but, due to the pandemic-related restrictions, I did not accomplish the latter. As a consequence, I had to partially reassess my plan for this thesis. The specific deviations from what I had planned are described in detail in Chapter 8 on the electroencephalography study, which was supposed to be a much larger part of my research. Despite these re-adjustments, I still strongly believe that this thesis presents a worthwhile piece of research on an important, yet under-studied topic.

Chapter 2

Study Protocol

The subsequent chapters (with the exception of Chapter 8) are all based on different aspects of a large cross-sectional study conducted during the first half of my PhD studies. This chapter features a detailed protocol of the study, to serve as a reference.

2.1. Participants

The study was conducted at Procter & Gamble, Research & Development Baby Care, German Innovation Centre (Schwalbach am Taunus, Germany). The participants were recruited from a pool of families living in the Taunus area, who expressed interest in research taking place at the facility. The participants were recruited into two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and 18 females) and 11- to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females). Sixty-nine of the primary caregivers identified as female, and the remaining two identified as male. Inclusion criteria for the study were: infant gestational age at the time of birth > 37 weeks, no diagnosed developmental disorders and German fluency (caregiver). The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the Research Ethics Committee at the Department of Psychological Sciences, Birkbeck, University of London.

2.2. **Measures**

2.2.1. Measures of caregiver touch

2.2.1.1. *Parent Infant Caregiving Touch Scale (PICTS) – adapted version*

To the best of my knowledge, the Parent-Infant Caregiving Touch Scale (PICTS; Koukounari et al., 2015), which measures self-reported frequency of specific touch-related caregiving behaviours, is the only parental questionnaire currently used to assess caregiver touch given to infants. It is a short, 12-item scale designed to capture commonly occurring parental behaviours. Four items refer to stroking of different body parts, and the rest are about other forms of touch and communication: picking up, cuddling, rocking, kissing, holding, talking to, watching, and leaving the baby to lie down. Parents are asked to indicate how often they engage in those behaviours by choosing a level on a 5-point Likert scale ranging from Never (1) to A Lot (5). While this questionnaire is simple, it also has good psychometric properties. Koukounari et al. (2015) found its test-retest reliability at 5 and 9 weeks to be very good. The factor structure of PICTS at 9 weeks is depicted in Figure 2.1.

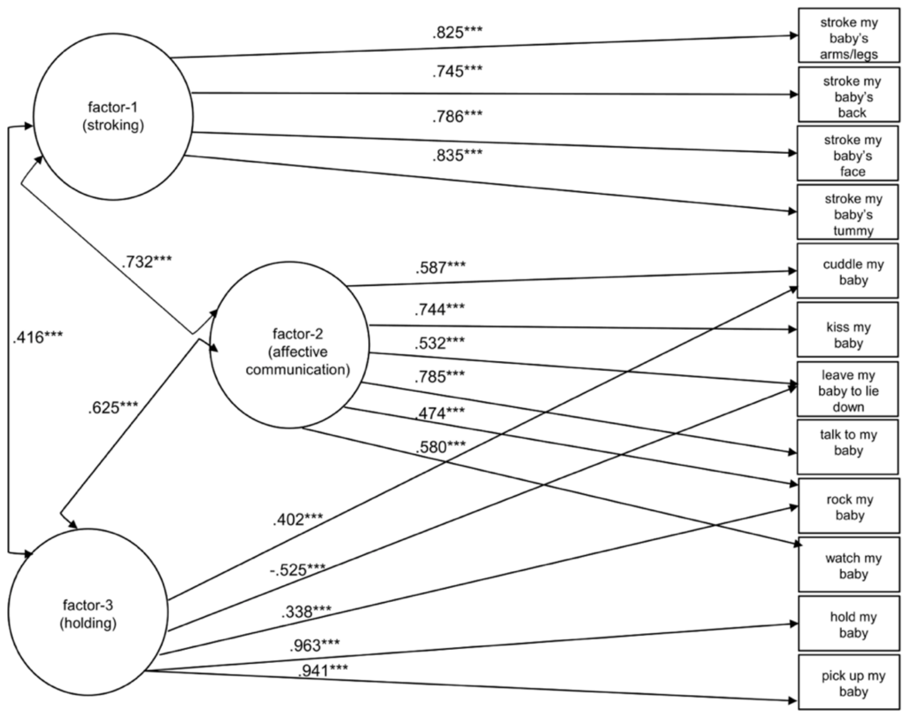

Figure 2.1. PICTS factor structure at 9 weeks. Standardised estimates of loadings are displayed from the factors (shown in circles) to the 12 ordinal original items (shown in squares). Arrows between the factors represent the standardised values of their covariances. ***P <.001. Taken from Koukounari et al., 2015.

An adapted version of the Parent Infant Caregiving Touch Scale (Koukounari et al., 2015) was used as a first self-report measure of caregiver touch. The questionnaire was translated into German, and in addition to the original items (all shown in Figure 2.1.), two extra items were added: *I sleep in the same bed with my baby* and *I carry my baby in a sling*. I added the two additional items because they tap into an interesting dimension of proximity, and likely capture parental touch in non-playful or infant-focused contexts. A more detailed description of the instrument can be found in Chapter 3.

2.2.1.2. *Social Touch Questionnaire (STQ)*

The Social Touch Questionnaire (STQ; Wilhelm, Kochar, Roth, & Gross, 2001) is a questionnaire originally designed to measure attitudes and affect towards social touch, with a focus on capturing potential anxiety and embarrassment associated with it. The STQ consists of statements about experiences of touch with both close, familiar people (e.g. *As a child, I was often cuddled by family members*) and strangers (e.g. *I would rather avoid shaking hands with strangers*). Participants are asked to indicate how characteristic or true each of the statements are of them on a 0-4 scale (from "not at all" to "extremely"). Higher STQ scores reflect more anxiety and embarrassment and less positive experiences with social touch. Our version of the STQ was translated into German, and three items were removed, as I deemed them either not applicable to our study participants (*I'd feel uncomfortable if a professor touched me on the shoulder in public*) or associated with romantic, intimate affection (*I like being caressed in intimate situations* and *I feel disgusted when I see public displays of intimate affection*). The adapted STQ version consisted of the remaining original seventeen items. A more detailed description of the instrument can be found in Chapter 3.

2.2.1.3. *Touch Diary*

A second self-report measure of caregiving behaviours used in our study was a custom online Touch Diary, based on diaries previously used in other studies (Barr et al., 1988; Lam et al., 2010). In the diary, primary caregivers were asked to estimate the number of minutes they spent each hour over a period of 24 hours holding (please note that the original German word used 'kuscheln' is closer in meaning to 'cuddling'), stroking, and talking to their infant, every day for seven consecutive days. To indicate the number of minutes, they used slider-like scales (see Figure 2.2.). The diary was hosted on the online platform SurveyMonkey, which formats the questionnaires in a smartphone-friendly way. Parents received separate emails with links to the diary for seven consecutive days, and were encouraged to fill them out on their smartphones. The instructions emphasised that while they should aim for their answers to reflect their actual behaviours, it is understood that they can only be approximate in their estimations. They could open the diary for a given day multiple times, and were asked to fill it out whenever convenient.

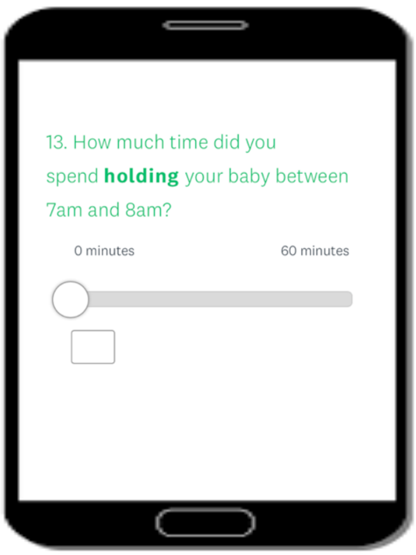

Figure 2.2. The smartphone-based interface of the Touch Diary with slider-like scales

2.2.1.4. *Parent-Child Interaction*

Interactions between parents and their children were filmed and later coded for parental touch patterns. Parent-child interaction (PCI) was observed in two situations: 10 minutes of free play (PCI-FP) and 10 minutes of parent answering questions (PCI-Q) from the Infant Behaviour Questionnaire – Very Short Version (IBQ-R; Putnam, Helbig, Gartstein, Rothbart, & Leerkes, 2014). The interactions took place in a room without toys, equipped with a bean-bag and two cushions (see Figure 2.3.).

The moment when the experimenter left the room was considered the beginning of PCI-FP, while for PCI-Q the beginning was the moment when the experimenter begun to ask the questions. In PCI-Q, if the caregiver answered all the questions from the IBQ-R questionnaire before 10 minutes passed (which happened very rarely), the experimenter continued with small talk about the child. In the more common case in which not all the questions were answered during those 10 minutes, the experimenter stopped asking the questions once 10 minutes passed and the caregiver was asked to fill out the missing items at the end of the visit, when they were given the PICTS and the STQ questionnaires.

The PCI videos were later coded offline, using a custom coding scheme based on criteria adapted and modified from Stack et al. (2014); details of the coding scheme are presented in Table 2.1.

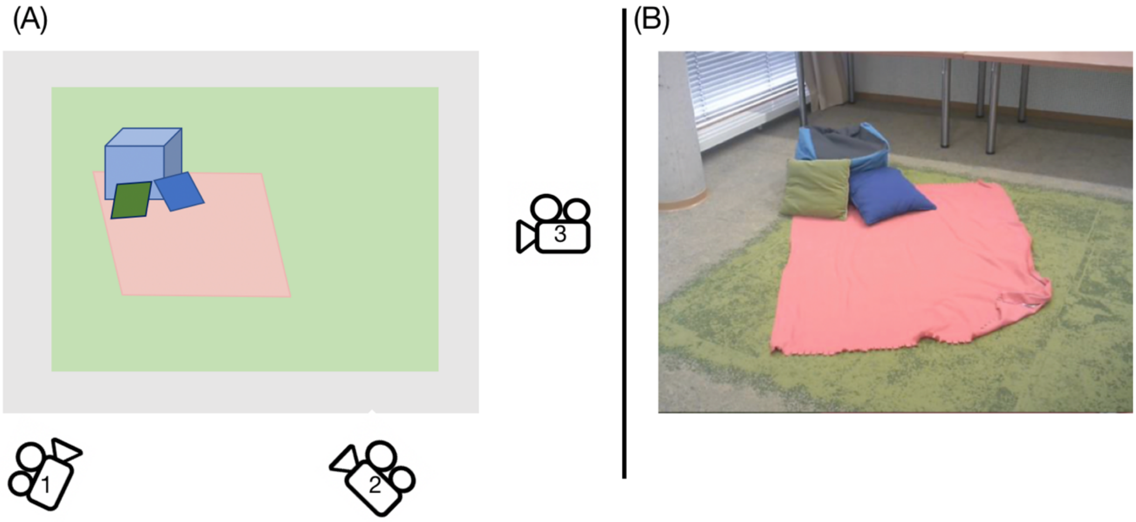

Figure 2.3. Schematic picture of the room where PCI-FP and PCI-Q took place, including the camera positions (A) and a snapshot of the view of the room from camera number 2 (B)

Table 2.1. Parent Child Interactions coding scheme (adapted from Stack et al., 2014)

touch category	properties/description
stroke/caress	CT-targeted touch
kiss/pat	light, brief touch
hug/hold/cradle	constant pressure applied on large part of body; warmth
massage	dynamic deep pressure
touch with objects	incl. wiping mouth, fixing clothes
moving limbs/body	proprioceptive touch
tickle	unpredictable touch
games/routines played on body	predictable touch
static	constant pressure applied on small part of body
rocking	predictable and proprioceptive touch

2.2.2. Measures of infant hormonal response/arousal

2.2.2.1. *Salivary oxytocin*

I obtained infant saliva samples using Salivettes® (Sarstedt, Rommelsdorf, Germany). The parents were asked not to feed their children 45 minutes prior to their arrival to the lab. Samples were collected at the beginning of the dyad's visit in the lab, shortly after acquainting the infant-caregiver pair with the lab, and after a ~40 minutes long period of parent-infant interaction, resulting in a maximum of two samples per infant. Each time, parents were asked to put on a glove and put the Salivette® in their child's mouth for them to chew for 1 minute until it was saturated with saliva (see Nishizato et al., 2017).

2.2.2.2. *Salivary cortisol*

Infant saliva samples were obtained using Salivettes® Cortisol (Sarstedt, Rommelsdorf, Germany). Similarly to salivary oxytocin, samples were collected at the beginning of the dyad's visit in the lab (right after collecting the oxytocin saliva sample), shortly after acquainting the infant-caregiver pair with the lab, and after a ~40 minutes long period of parent-infant interaction The saliva collection procedure was identical to the one used for obtaining saliva samples for oxytocin, described above (section 2.2.2.1.).

2.2.2.3. *Heart rate*

A specially adjusted Polar H10 heart rate monitor belt was put on the baby. Validity of using such monitors to obtain short-term heart rate variability (HRV) measures, as compared with traditional electrocardiography, has been confirmed (Giles et al., 2016), and it appears to be a more infant-friendly technique, as it does not require attaching electrodes onto the baby's body. During the visit, heart rate activity of the baby was measured twice: at baseline, after obtaining the first saliva samples, and secondly, after the period of parent-child interaction. Each time the baby was sat in a high chair, watching a relaxing animation with fish swimming, and the parent was instructed to refrain from talking to the baby and touching them. The measurements lasted 2 minutes or until the baby became fussy.

The monitor records RR interval data, which can later be analysed in the frequency domain, by applying a fast Fourier transformation to it, for the identification of sympathetic and parasympathetic contributions of HRV (Giles et al., 2016; Zygmunt & Stanczyk, 2010). Two components: a high frequency (HF) component (0.15 – 1.0 Hz), which is identified with vagal tone and a low frequency (LF) component (0.04 – 0.15 Hz), which is thought to be mediated by both sympathetic and parasympathetic parts of the autonomic system, were of specific interest in this study, as their ratio (LF/HF ratio) is believed to reflect maturation and the ability to react effectively to stress – the lower the ratio, the more mature the response (Cong et al., 2009).

Unfortunately, in the course of the data collection, it turned out that there were significant problems with the heart rate measurements, as the heart rate monitor belt kept on losing contact with the infant's body (even after efforts to adjust it) for the majority of participants, resulting in poor quality and unreliable signal. Therefore, this measure was dropped from the analyses, but for the sake of protocol consistency between participants, all participants still had the heart rate monitor belts attached at the beginning of the session, and watched the animations.

2.2.3. Measures of infant exploratory behaviour

2.2.3.1. Table top-based measures

For the table top-based measures, the infant was sat in a high chair at the table, with their caregiver and the experimenter sitting behind them (see Figure 2.4.). For both tasks, the baby was presented with toys: one at a time (Sequential exploration toy task, section 2.4.1.1.) or nine at once (Simultaneous exploration toy task, section 2.4.1.2.). The caregiver was instructed to refrain from helping or interacting with their baby, and if the baby explicitly sought their attention, to respond with “Nice!” or “Good job!”. If the baby dropped a toy, the experimenter retrieved it as soon as possible, putting it back on the table/tray in front of the baby. If a toy was dropped three times, the experimenter removed it completely.

Figure 2.4. Infant performing the sequential object exploration task (left) and simultaneous object exploration task (right)

2.2.3.1.1. *Sequential exploration toy task*

During this task, 9 toys varying in size, shape, texture, hardness, colour and existence of moving parts are presented to the child by the experimenter for 30 seconds each. The toys used in this task are depicted in Figure 2.5. The procedure is an adaptation of tasks previously used by Putnam & Stifter (2005) and Lobo et al. (2015).

Figure 2.5. Toys presented to the child during the sequential exploratory task

2.2.3.1.2. *Simultaneous exploration toy task*

In this task, the child is presented with a tray with 9 different toys (see Figure 2.6.) for 5 minutes, or until the infant lost interest (as indicated by the lack of any engagement with the toys) for at least 20 seconds). This procedure is adapted from Van den Boom (1994), who used it with children aged 6-, 9- and 12-months.

Figure 2.6. Toys presented to the child during the simultaneous exploratory task

2.2.3.2. Eye tracking-based measures

The eye tracking tasks were performed in a room specifically set up for this purpose at the Research & Development Baby Care German Innovation Centre, P&G (see Figure 2.7.). The eye tracker used was a 120 Hz Tobii x120, and the tasks were presented on an HP E242 monitor (1920 x 1200 pixels, 24”). The baby was sat in a car seat, which was held by their parent on their lap, and the parent was sitting on a desk chair. Custom-written MATLAB scripts were used to present the stimuli. The scripts used were a part of a testing battery created by the BASIS (The British Autism Study of Infant Siblings) team from the Centre for Brain and Cognitive Development at Birkbeck University of London.. The task trials were presented in a fixed order, alternating between trials from different tasks to keep the infant engaged – see Table 2.2. for the exact order of the trials. Between each task trial, a gaze-contingent animated fixation was presented to guide the infant’s attention to the centre of the screen. The duration of the eye tracking session was about 15 minutes on average. If the baby became fidgety or distressed, the presentation script was paused in between trials, and the parent was encouraged to interact with the baby to calm them down (sometimes the experimenter blew bubbles to keep the baby engaged). If this happened more than two times, the eye tracking session was terminated.

Figure 2.7. Eye tracking lab set up at Procter & Gamble, Research & Development Baby Care, German Innovation Centre

Table 2.2. The order of the task trials in the eye tracking task battery

Order	Task trial name
1	Multisensory Integration Task, trial 1
2	Face Pop Out Task, trial 1
3	Sustained Attention Task, trial 1
4	Face Pop Out Task, trial 2
5	Multisensory Integration Task, trial 2
6	Non-social Pop Out Task, trial 1
7	Sustained Attention Task, trial 2
8	Face Pop Out Task, trial 3
9	Multisensory Integration Task, trial 3
10	Non-social Pop Out Task, trial 2
11	Face Pop Out Task, trial 4
12	Multisensory Integration Task, trial 4
13	Non-social Pop Out Task, trial 3
14	Face Pop Out Task, trial 5
15	Sustained Attention Task, trial 3
16	Face Pop Out Task, trial 6
17	Non-social Pop Out Task, trial 3
18	Multisensory Integration Task, trial 5
19	Face Pop Out Task, trial 7
20	Sustained Attention Task, trial 4

2.2.3.2.1. *Face Pop Out task (eye tracking)*

In this task, infants are presented with a complex visual array containing faces among 5 other visual objects (Gliga et al., 2009). Example slide is shown in Figure 2.8. In this study, it is used to asses infants' interest in faces as compared to non-social stimuli, to verify whether touch and related measures of arousal can affect the distribution of attention.

Figure 2.8. Example slide from the Face Pop Out task

2.2.3.2.2. *Non-social Pop Out task (eye tracking)*

This task is analogous to the face pop-out task (Gliga et al., 2009), but the arrays of objects do not contain faces, but only non-social objects (see Figure 2.9.). It is used to assess infant's patterns of visual exploration of objects, and it is supposed to be an eye tracking equivalent of the simultaneous exploratory task.

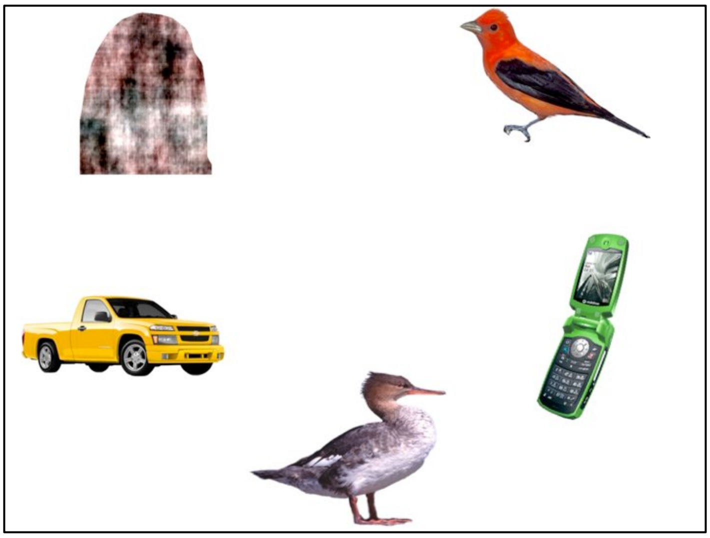

Figure 2.9. Example slide from the Non-social Pop Out task

2.2.3.2.3. *Sustained attention task (eye tracking)*

In this task, the infant is presented with two 'interesting' (complex, detailed) and two 'boring' (noncomplex) static stimuli (adapted from: Goodwin et al. (2016) and Wass et al. (2011); see Figure 2.10. If the infant disengages from the stimulus for longer than 1 second, an audio-visual animated attention-grabber is presented until the infant re-engages. Each stimulus appears on the screen until five separate looks are recorded. If a single look lasts 40 seconds, the presentation of the stimulus is terminated.

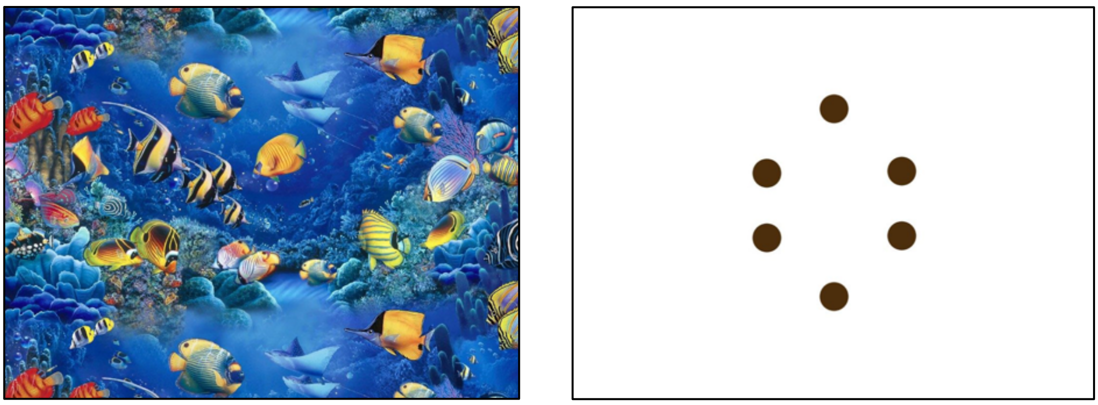

Figure 2.10. An example of an interesting stimulus slide (left side) and boring stimulus slide (right side)

2.2.3.2.4. *Multisensory integration task (eye tracking)*

In this task, the infant is presented with two animated balls, one on the left and one the right side of the screen, within two rectangles (see Figure 2.11.). The balls move on a linear path until hitting the walls, when they are deflected and continue their movement. The balls move on different trajectories and therefore hit the walls at different times. A sound is played coincidental to one of the balls `hitting a wall ('multisensory ball') but not the other ball ('unisensory ball'). It is assumed that if the infant notices this relation, they should look at the multisensory ball more. This is likely to reflect the fact that the movement of that ball provides information about the upcoming sound. The measure of interest is proportion of time spent looking at the multisensory ball.

This task was not used in the analyses described in the current thesis, but additional analyses are reported in Appendix A.

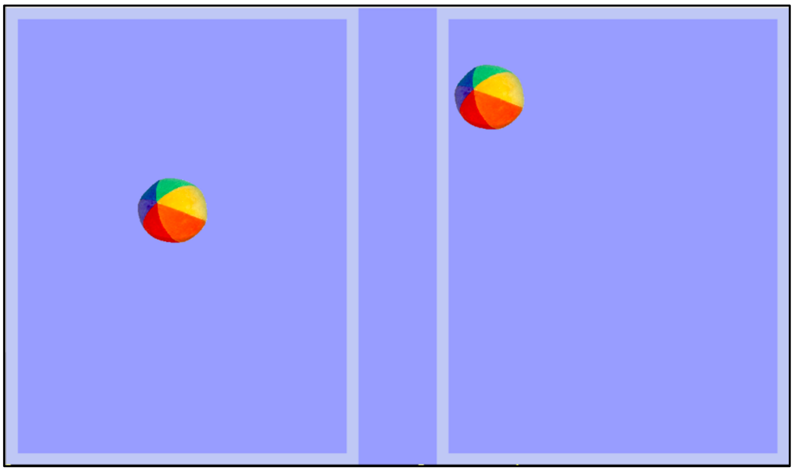

Figure 2.11. An example frame from the multisensory integration task.

2.2.4. Other measures

2.2.4.1. *Infant Behaviour Questionnaire-Revised – Very Short Version (IBQ-R VS)*

The IBQ-R VSV is a well-established caregiver report measure of temperament for infants aged 3 to 12 months (Putnam et al., 2014). It is based on a definition of temperament as constitutionally based individual differences in reactivity and self-regulation, influenced over time by heredity and experience (M.K. Rothbart & Bates, 2006). The very short form of IBQ-R measures three factors: Negative Emotionality (NEG), Positive Affectivity/Surgency (PAS) and Orienting/Regulatory Capacity (ORC). The PAS factor is made up of Approach, Vocal Reactivity, High Intensity Pleasure, Smiling and Laughter, Activity Level, and Perceptual Sensitivity, and it is thought of as the precursor of Extraversion. The NEG factor is composed of Sadness, Distress to Limitations, Fear and, with negative loadings, Falling Reactivity, and is roughly similar to the personality trait of Neuroticism. The ORC factor is made up of Duration of Orienting, Low Intensity Pleasure, Cuddliness, and Soothability; it has been shown to predict Effortful Control in toddlerhood and early childhood (Putnam et al., 2008, 2014), which in turn predicts adult personality trait of Conscientiousness (Putnam et al., 2014; Rothbart et al., 2000).

2.3. Procedure

Infants and their caregivers were brought into the lab and provided informed consent before the start of the study. The caregivers were made aware that their behaviour during the entire duration of the visit will be filmed (unless they withdraw their consent), but were not told that we were specifically interested in touching behaviours until the end of the visit. Following a short time allowing participants to familiarise themselves with the setting, saliva samples were taken from the infant by the caregiver using Salivette® Cotton Swabs (Sarstedt, Rommelsdorf, Germany), and a heart rate recording device (Heart Rate band Polar H7 – a device on a strap) was put on the baby's chest. Next, the baby was presented with a two minute long animation during which heart rate measurement was taken, after which the experimenter turned on three video cameras and the parent was informed that from now on, everything happening in the room would be video recorded until the experimenter said otherwise. Then, the parent was asked to change the baby's diaper and, when they were done, Parent-Child Interactions, Free Play (PCI-FP) and Questions (PCI-Q), began.

Both interactions took place in the same room, one after the other. In order to create an environment where potential caregiver touch would be maximised, the room was not equipped with any toys, only a blanket, a bean-bag and two cushions (see Figure 2.3).

For PCI-FP, parents were instructed to play with their children like they normally would at home, without any toys, and if possible, to remain close to the area marked out by the blanket, for the cameras to be able to capture the interaction. The experimenter was not present in the room, but observed the interaction through a one-way mirror in an adjacent room, a fact which parents were made aware of. After ten minutes of free play, the experimenter returned to the main room, sat down on the blanket, and asked questions from the IBQ-R for another ten minutes; this constituted the PCI-Q part of the procedure. Afterwards, the baby was again presented with the same animation, saliva samples were collected, and the baby then participated in the table top and eye-tracking tasks. At the end of the visit, the parent filled in the Parent-Infant Caregiving Scale and Social Touch Questionnaire. They were also given instructions for the Touch Diary and were informed that completing all seven days of the diary would qualify them to participate in a draw to win a 50 euro Amazon voucher. The links to each day entry of the Touch Diary were sent to the parents every day for seven consecutive days, with the first one being sent on midnight the day following the visit in the lab, and the next ones following every 24 hours.

The entire parent-infant dyad visit at the lab lasted on average between one and a half and two hours. A summary of the time course of the visit is shown in Figure 2.12.

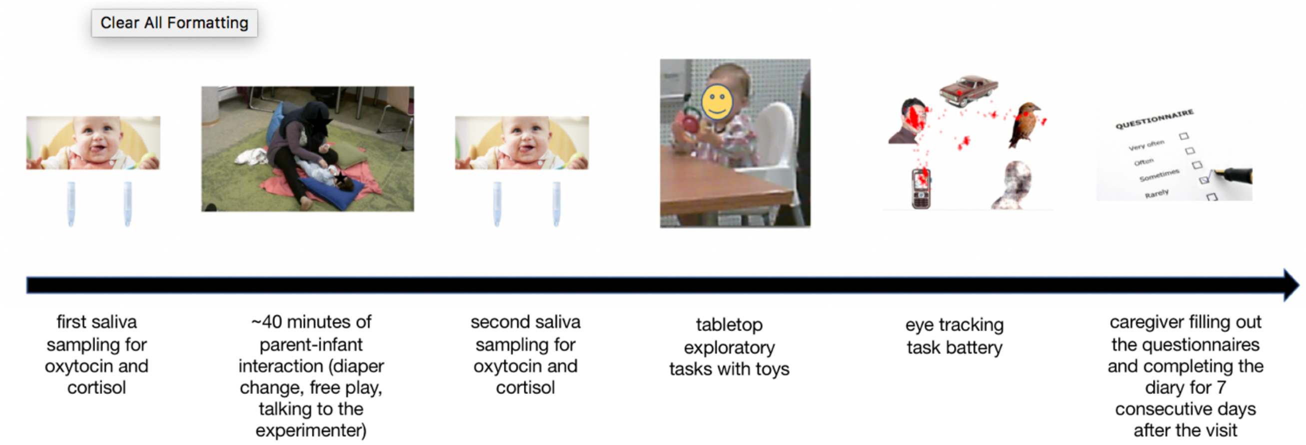

Figure 2.12. Schematic time course of the dyad's visit in the lab

Having presented an overview of the main methods, I now turn to the first experimental chapter whose aim was to explore various methods of capturing touch in parent-infant interaction.

Chapter 3

Capturing caregiver touch in parent-infant interaction

Chapter 3 is based on the following article:

Brzozowska A., Longo M.R., Mareschal D., Wiesemann F., Gliga T. (2021) Capturing touch in parent– infant interaction: A comparison of methods. *Infancy*, 00:1– 21.

3.1. Introduction

Considering the apparent significance of touch in the first months of life, it is striking how little research there is on the specific effects and mechanisms through which it shapes human infant development. One explanation lies with the practical and ethical challenges associated with studying human caregiver touch. One clear difference between measuring caregiver touch in non-human animals and in humans is that in the former case, researchers are able to observe the participants continuously. Touching behaviours in animals are easily identifiable – for example licking/grooming, and arched-back nursing (LG-ABN) in rats (Caldji et al., 1998) – and can be quantified over long periods of time. This results in representative estimates of caregiver tactile stimulation, and can be used to accurately identify caregivers who engage in low- or high-levels of contact. In addition, much of the evidence for the important role of touch in development comes from experiments which employed cross-fostering, a practice in which rat offspring of low LG-ABN mothers are artificially assigned to be fostered by high LG-ABN mothers, and vice versa (Francis, Diorio, Liu, & Meaney, 1999). While cross-fostering is an elegant example of a study design allowing for robust inferences about the impact of maternal touch-related behaviours in infancy, for obvious reasons such studies are not possible with humans. When aiming to examine correlates of parental touch-related behaviours, especially when the focus is on patterns occurring over longer periods of time, researchers studying human development have much more limited options.

Several studies with human participants have looked into populations where it has been documented that caregiver touch is minimal, such as infants in institutionalised care (Maclean, 2003) and infants of depressed mothers (Field, 2001). In studies employing this approach, caregiver touch was assumed to be reduced, but was not actually quantified. Some studies with human infants have attempted to experimentally manipulate caregiver touch, an approach most notably exemplified by studies examining effects of touch-based interventions, i.e. Kangaroo Care

(Cong, Ludington-Hoe, & Walsh, 2011; Feldman, Eidelman, Sirota, & Weller, 2002) and baby massage (Field, Diego, Hernandez-Reif, Deeds, & Figuereido, 2006; Gitau et al., 2002). However, these investigations almost exclusively feature babies born prematurely, as the authors were particularly interested in helping these babies from a medical perspective. It is therefore hard to generalise the results of such studies beyond the specific atypical populations and rather extreme tactile experiences investigated.

While studies with infants of depressed mothers, those born prematurely, and infants in institutionalised care provide invaluable insights into the role that tactile deprivation and tactile enrichment play in early development, which are especially informative about atypical populations, it is important to understand whether naturally occurring variations in everyday caregiver touch are consequential for development in the general infant population, as has been found in animal work (Gliga et al., 2019). A variety of methods have been used to capture the amount and nature of touch in parent-child interaction. These methods differ in whether they are subjective, like parent-report measures, including questionnaire (Koukounari et al., 2015) and diaries (Barr et al., 1988; Lam et al., 2010), or objective, as for example measures coded from recordings of parent-child interactions (Feldman, Gordon, Schneiderman, Weisman, & Zagoory-Sharon, 2010; Reece, Ebstein, Cheng, Ng, & Schirmer, 2016). They also vary in how often these measures are taken (i.e. one off questionnaires or diaries), and the length of recorded observation. Methods most commonly employed for this purpose are discussed below.

3.1.1. *One-off parent-report questionnaires*

Parent-Infant Caregiving Touch Scale (PICTS). To the best of my knowledge, the Parent-Infant Caregiving Touch Scale (PICTS; Koukounari et al., 2015), which measures self-reported frequency of specific touch-related caregiving behaviours, is the only parental questionnaire currently used to assess caregiver touch given to infants. It is a short, 12-item scale designed to capture commonly occurring parental behaviours. Four items refer to stroking of different body parts, and the rest are about other forms of touch and communication: picking up, cuddling, rocking, kissing, holding, talking to, watching, and leaving the baby to lie down. Parents are asked to indicate how often they engage in those behaviours by choosing a level on a 5-point Likert scale ranging from Never (1) to A Lot (5). While this questionnaire is simple, it also has good psychometric properties. Koukounari et al. (2015) found its internal reliability at 5 and 9 weeks to be very good. Interestingly, PICTS scores were not related to other measures of caregiving quality such as maternal sensitivity (as rated from parent-child interactions). While the authors took it to mean that touch has a distinct function in parent-child interaction, this lack of correlation could also raise questions about the validity of this scale. As a self-report measure, it could be subject to "faking good", or performing for the researcher (Field, 2019), with parents reporting inflated levels of caregiving behaviours. Nevertheless, stroking, operationalised as the 'stroking' factor in the PICTS scale (composed of the four items asking about stroking baby's arms/legs, back, face, and tummy), has been reported to have buffering effects on developmental outcomes of children whose mothers experienced pregnancy-specific anxiety (PSA), in that high levels of stroking in infancy significantly reduced the effects of PSA on internalizing and externalizing scores at 3.5 years (Pickles et al., 2017). Moreover, a recent study found a moderating effect of parental stroking on 9-month-olds' heart rate response to gentle stroking – the more stroking the parent reported in the PICTS questionnaire, the larger were the immediate decelerating effects of stroking on baby's heart rate (Aguirre et al., 2019). The mechanisms behind these effects are likely similar to the stress-buffering effects of licking and grooming in rodents (Suchecki et al., 1993), but much more research is needed before we fully understand these phenomena in human infants.

The Social Touch Questionnaire (STQ; Wilhelm, Kochar, Roth, & Gross, 2001) is a questionnaire originally designed to measure attitudes and affect towards social touch, with a focus on capturing potential anxiety and embarrassment associated with it. The STQ consists of statements about experiences of touch with both close, familiar people (e.g. *As a child, I was often cuddled by family members*) and strangers (e.g. *I would rather avoid shaking hands with strangers*). Participants are asked to indicate how characteristic or true each of the statements are of them on a 0-4 scale (from "not at all" to "extremely"). Higher STQ scores reflect more anxiety and embarrassment and less positive experiences with social touch. Previous work (Aguirre et al., 2019) found an association between infant physiological reactions to touch and parental attitudes towards touch. This raises the possibility that parental attitudes may be a reliable predictor of parents' use of touch including in parent infant interaction.

Although previous work suggests that both PICTS and STQ may be valid measures of parental touch, to date no study validated them against objective measures of caregiver touch.

3.1.2. *Diaries*

Another approach to measuring caregiver touch through parental self-report is the use of diaries, either in paper or electronic (online) form. Such diaries commonly ask parents to record caregiving (e.g. holding) and/or infant (e.g. crying) behaviours over a period of a couple days (Barr et al., 1988; Lam et al., 2010). Thus, one advantage of diaries is that they provide a record of behaviours of interest over a certain period of time, typically around a week, potentially resulting in estimates more representative of everyday behaviour patterns across a variety of contexts than ones collected at a single time point, while being sensitive to day-to-day differences in caregiving behaviours. In addition, diaries differ from one-off questionnaires like the PICTS in that they typically ask about the durations of certain behaviours in terms of minutes or hours. Some have claimed that diaries do provide accurate gauges of the frequency and duration of behaviours of interest, while being relatively easy to use for both the parents and the researchers (Lam et al., 2010), but those claims have not been supported by validation with independent measures.

However, diaries have also been reported to be onerous for participants, with some participants indicating that they do not have time for their completion, and others just not following through with their participation, consequently yielding response rates that often do not enable conclusive analyses (Nicholl, 2010). It also remains unclear to what extent event duration estimations obtained from diaries are accurate. These concerns are most likely the reason why very few studies on caregiver touch to date have used diaries. One exception is a recent study (Moore et al., 2017) on the associations between caregiver touch in infancy and epigenetic signatures at 4-5 years of age, focusing on genes associated with social bonding and postnatal plasticity, where they found no statistically significant correlations between postnatal contact and candidate genes. Considering the abovementioned concerns about diaries, such studies can be hard to interpret, and learning more about diaries in terms of their psychometric properties would certainly help shed more light on results such as the ones observed by Moore et al. (2017).

3.1.3. *Observing Parent-Child Interaction*

The most common way of measuring caregiver tactile contact with their baby is within some sort of a parent-child interaction (PCI) setup, where the behaviour of the dyad is filmed and later video-coded for events of interest. The straightforwardness of this method makes it very attractive, as researchers are able to directly observe the caregiver behaviours they are interested in, without having to rely on the accuracy of parent self-report. PCI-derived measures also enable flexibility with regard to the behaviours of interest, allowing researchers to choose a coding scheme that best reflects their interests.

Most commonly, touch in caregiver-infant interactions is measured within a free play setting, including face-to-face setups where infants are sat in a car seat with mothers sat opposite them (Feldman, Singer, & Zagoory, 2010; Moreno, Posada, & Goldyn, 2006; Stack & Muir, 1992) or interactions on the floor, where parents are free to position the infant however they please (Feldman, Weller, Sirota, & Eidelman, 2003; Jean & Stack, 2009). The instructions given to parents are usually aimed at evoking naturalistic interactions, with phrasings such as "*Play freely*" (Feldman, Singer, et al., 2010), "*Play with your baby as you normally would* " (Moreno et al., 2006), or *"Play like you would normally do at home"* (Jean et al., 2009). The interactions are typically coded over a period of time varying from 3 (Feldman, Singer, et al., 2010) to 6 minutes (Moreno et al., 2006).

Various approaches to quantifying touch events have been adopted, with some focusing on duration (Moreno et al., 2006) and others on number of instances of touch (Reece et al., 2016). Multiple coding schemes have been employed, with some focusing on low-level, descriptive touch properties such as 'static', 'tickle', or 'pat' (e.g. Stack et al., 1996), and some targeting higher-level touch features, with coding categories like 'affectionate touch', 'stimulatory touch' or 'proprioceptive touch' (Feldman, Gordon, et al., 2010). Sometimes, studies investigating general caregiving qualities include touching behaviours in their coding schemes, collapsed together with other behaviours in broader categories like 'maternal engagement' (e.g. Krol, Moulder, Lillard, Grossmann, & Connelly, 2019). However, some authors have pointed out that coding schemes used in studies on maternal sensitivity and attachment largely omit or do not take an in-depth approach to observing touch (Botero et al., 2019). Even the approaches that aim to capture low-level properties of touch tend to merge touching behaviours that may have different functions and mechanisms. An example of this would be Stack et al. (1996) including stroking and caressing in the same category as rubbing and massaging, even though the former have been shown to have distinct neurobiological mechanisms, associated with a special type of fibres called CT afferents (McGlone et al., 2014). Only relatively recently have stroking and caressing started to be treated as a separate category in coding schemes (e.g. Stack et al., 2014). Moreover, while being a relatively objective measure, PCIs observed in a lab, or even in a home setting, are quite an artificial situation for caregivers to find themselves in, likely affecting their behaviours in non-negligible ways. The vast majority of PCI-based protocols focus on playful interactions, which may not be representative of a large proportion of everyday parent-infant contact.

3.1.4. The present study

Very few studies have used more than one measure of caregiver touch, and the large diversity of methods employed in different studies makes it hard to interpret and generalise the findings. It is possible that the existing measures aimed at capturing equivalent touching behaviours actually tap into different aspects of caregiver touch. Existing measures also rely on the accuracy of parental self-report, or the representativeness of a short period of child-focused interaction. The aim of the present study was to examine, for the first time, whether different approaches to measuring caregiver touch, one-off questionnaires, diaries and objective observations, are related, in order to establish the extent to which they measure similar, or possibly different aspects of caregiver touch.

One other innovation is in the way touch was measured in parent-child interaction. It is likely that a large proportion of touching behaviours (or lack thereof) between parent and infant occur in non-playful situations, like preparing a meal, or having a conversation with another adult. Use of touch in these situations possibly differs both qualitatively and quantitatively from parental touching behaviours during playful, infant-focused situations, the classical setting in which touch is observed. Individual variation may be higher in these situations, with some parents preferring to keep closer contact with the child than others. Similarly, self-report measures may also capture behaviours in situations in which parents are focusing their attention on infants, and therefore are more conscious of whether and how they use touch. This is why I included both a free-play session (PCI-FP) and a PCI-Q condition in the study protocol, when parent was having a conversation with the experimenter (answering questions from a questionnaire). I assumed this condition is likely representative of a large proportion of everyday interactions between parents and children, therefore potentially capturing important variation in caregiver behaviour.

Thus, in this study touch was captured with an adapted version of PICTS, the Social Touch Questionnaire, a custom Touch Diary, and PCI-derived touch measures. I was interested in whether there are associations between putative equivalent measures from the questionnaire and diary approaches by looking at how they correlate with behaviours observed in the lab. In particular, I investigated the general structure of the data by observing whether measures map onto one or more common factors. One possibility is that I could observe a clear distinction between self-report and the play-focused observed measure, consistent with the former being subject to 'faking good', or the latter not being representative of touch in real life. Another goal was to take a more in-depth look at the spectrum of touching behaviours we can observe in the lab, with a focus on comparison between free play and a non-play/task-focused situation.

Touch behaviours decrease during the first 6 months of life (Jean et al. 2009), and may decrease further as children become mobile and other means of interaction are more frequently employed. Few studies to date have investigated caregiver touch beyond the sixth month of infant life. I therefore included in the study a broad age range (6 to 13-month olds) to enable us to investigate developmental dynamics of parental touching of children who are less reliant on being carried, therefore potentially making it easier to observe individual differences in parental behaviours. Measures that are more biased towards 'faking good' are likely to capture less developmental changes in touch behaviour.

3.2. Methods

3.2.1. Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and

18 females) and 11- to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females) and their primary caregivers.

Because the current work is not based on hypotheses about the moderating role of infant developmental status (as approximated by age) on the investigated associations, I therefore pooled the participants into one group of seventy-one infants aged 6 to 13 months in order to increase statistical power and used age as a continuous variable in analysis. The sample size compares rather favourably to those in previous studies employing video-coded measures of caregiver touch (e.g., Feldman et al., 2010: n = 53; Jean & Stack, 2009: n = 40).

3.2.2. *Measures*

3.2.2.1. *Parent Infant Caregiving Touch Scale – adapted version*

An adapted version of the Parent Infant Caregiving Touch Scale (Koukounari et al., 2015) was used as a first self-report measure of caregiver touch. The questionnaire was translated into German, and in addition to the original items (see: 1.2.), two extra items were added: *I sleep in the same bed with my baby* and *I carry my baby in a sling*. I added the two additional items because they tap into an interesting dimension of proximity, and likely capture parental touch in non-playful or infant-focused contexts.

The original version of PICTS has a three-factor structure, composed of Stroking, Affective Communication, and Holding. I treated the three factors as subscales (Ahmadzadeh et al., 2019), and included a fourth subscale (Proximity) comprising the two extra items. A score for each subscale was simply computed as a sum of scores for each item loading onto the respective factor. I decided to also compute a total score (PICTS Total), composed of all items in the questionnaire, in order to get a general measure of touching behaviours. The item *I leave my baby to* *lie down* loads positively onto the Affective Communication factor, but negatively onto the Holding factor (Koukounari et al., 2015). Thus, for both the Holding subscale and the total PICTS score these items were reverse-scored. For the total score and the subscale scores, the higher the scores, the more often the parent engages in touch-related aspects of caregiving.

3.2.2.2. *Social Touch Questionnaire*

Our version of the STQ was translated into German, and three items were removed, as I deemed them either not applicable to our study participants (*I'd feel uncomfortable if a professor touched me on the shoulder in public*) or associated with romantic, intimate affection (*I like being caressed in intimate situations* and *I feel disgusted when I see public displays of intimate affection*). The adapted STQ version consisted of the remaining original seventeen items. Higher scores indicate more anxiety and embarrassment and less positive experiences with social touch.

3.2.2.3. *Touch Diary*

A second self-report measure of caregiving behaviours used in our study was a custom online Touch Diary, based on diaries previously used in other studies (Barr et al., 1988; Lam et al., 2010). In the diary, primary caregivers were asked to estimate the number of minutes they spent each hour over a period of 24 hours holding (please note that the original German word used 'kuscheln' is closer in meaning to 'cuddling'), stroking, and talking to their infant, every day for seven consecutive days. To indicate the number of minutes, they used slider-like scales, with the value "0 minutes" as the minimum, the value "60 minutes" as the maximum, and a 1 minute resolution. The diary was hosted on the online platform SurveyMonkey, which formats the questionnaires in a smartphone-friendly way. Parents received separate emails with links to the diary for seven consecutive days, and were encouraged to fill them out on their smartphones. The instructions emphasised that while they should aim for their answers to reflect their actual behaviours, it is understood that they can only be approximate in their estimations. They could open the diary for a given day multiple times, and were asked to fill it out whenever convenient.

3.2.2.4. *Parent-child interaction (PCI)*

Interactions between parents and their children were filmed and later coded for parental touch patterns. Parent-child interaction (PCI) was observed in two situations: 10 minutes of free play (PCI-FP) and 10 minutes of parent answering questions (PCI-Q) from the Infant Behaviour Questionnaire – Very Short Version (IBQ-R; Putnam, Helbig, Gartstein, Rothbart, & Leerkes, 2014). The IBQ-R is a questionnaire designed to assess infant temperament, with questions revolving around infant behaviour during the 7 days preceding the assessment (example items: *When tired, how often did your baby show distress?* and *During a peekaboo game, how often did the baby laugh?*). It is worth noting that while the PCI-Q condition was designed to capture parental behaviour in non-infant-focused interactions, the topic of the conversation with the experimenter was still the child. This could have potentially primed the caregiver to pay more attention to their caregiving behaviours.

The moment when the experimenter left the room was considered the beginning of PCI-FP, while for PCI-Q the beginning was the moment when the experimenter begun to ask the questions. In PCI-Q, if the caregiver answered all the questions from the IBQ-R questionnaire before 10 minutes passed (which happened very rarely), the experimenter continued with small talk about the child. In the more common case in which not all the questions were answered during those 10 minutes, the experimenter stopped asking the questions once 10 minutes passed and the caregiver was asked to fill out the missing items at the end of the visit, when they were given the PICTS and the STQ questionnaires.

The PCI videos were later coded offline, using a custom coding scheme based on criteria adapted and modified from Stack et al. (2014); the categories were: stroke/caress, kiss/pat, hold/hug/cradle, massage, touch with objects, moving limbs/body, tickle, games/routines played on body, static, and rocking (see detailed description in Table 2.1., Chapter 2).

Our aim was to capture the full spectrum of possible tactile behaviours occurring during PCIs, while focusing on low-level touch properties (e.g. kissing, holding). I found that such properties are easier to identify and label than other, putative higher-level touch properties (e.g., affectionate touch, stimulatory touch) used by coding schemes in some studies (e.g., Feldman, Gordon, Schneiderman, Weisman, & Zagoory-Sharon, 2010). Moreover, in the light of evidence that stroking/caressing is associated with distinct neurobiological mechanisms from other types of tactile stimulation (McGlone et al., 2014), it was important to us to code this touching behaviour separately.

Videos were coded frame by frame using Datavyu software (Datavyu Team, 2014), widely used for coding infant data (e.g. Crespo-Llado, Vanderwert, Roberti, & Geangu, 2018; Della Longa, Filippetti, Dragovic, & Farroni, 2020) at 30 frames per second. For both conditions, PCI-FP and PCI-Q, five minutes of interaction were coded, starting with the third and ending with the seventh minute of the interaction in each condition. The categories were not mutually exclusive, meaning that multiple types of touch (e.g. 'hold/hug/cradle' and 'kiss') could occur at the same time. Total duration for every touch category was later calculated by adding up durations of each touch event. The total duration of overall touch, i.e. any time the infant was being touched at all during the five minutes of interaction being coded, was also computed in both PCI conditions. Inter-rater reliabilities were calculated on 20% of interactions using a two-way mixed, consistency single-measures intra-class correlation (ICC; Hallgren, 2012; McGraw & Wong, 1996). The first author was the primary coder, whose data was used in the analyses. Although, naturally, she was not naïve to the hypotheses of the study, at the time of coding, the PCI-FP and PCI-Q videos were not linked to the questionnaire and diary scores. The secondary coder did not have access to these scores at all. For the total duration of touch, which was the only coding-based measure used in correlational and PCA analyses, the ICC was 0.92, indicating excellent reliability (Cicchetti, 1994). In case of the specific touch categories, the ICCs ranged from excellent (0.99 for hug/hold/cradle and rocking, 0.97 for games/routines played on body, 0.94 for stroke/caress, 0.88 for moving limbs/body) through good (0.62 for static) and fair (0.59 for touching with objects) to poor (0.35 for tickle and 0.01 for massage) (Cicchetti, 1994). Although the latter two categories of touch, tickling and massage, need to be interpreted with caution, the remaining ICC values are in the acceptable range, and comparable with those in other studies using this approach (e.g. Reece et al., 2016).

3.2.3 Procedure

The data presented here were collected as a part of a larger study investigating the relationships between caregiver touch and infant developmental outcomes. Other measures such as salivary cortisol and oxytocin, heart rate, and infant performance in table top and eye-tracking tasks measuring infant exploratory behaviour and attention were taken (see Chapter 2 for details).

Infants and their caregivers were brought into the lab and provided informed consent before the start of the study. The caregivers were made aware that their behaviour during the entire duration of the visit will be filmed (unless they withdraw their consent), but were not told that I was specifically interested in touching behaviours until the end of the visit. Following a short time allowing participants to familiarise themselves with the setting, saliva samples were taken from the infant by the caregiver using Salivette® Cotton Swabs (Sarstedt, Rommelsdorft, Germany), and a heart rate recording device (Heart Rate band Polar H7 – a device on a strap) was put on the baby's chest. Next, the baby was presented with a two minute long animation during which heart rate measurement was taken, after which the experimenter turned on three video cameras and the parent was informed that from now on, everything happening in the room would be video recorded until the experimenter said otherwise. Then, the parent was asked to change the baby's diaper and, when they were done, Parent-Child Interactions, Free Play (PCI-FP) and Questions (PCI-Q), began.

For PCI-FP, parents were instructed to play with their children like they normally would at home, without any toys, and if possible, to remain close to the area marked out by the blanket, for the cameras to be able to capture the interaction. The experimenter was not present in the room, but observed the interaction through a one-way mirror in an adjacent room, a fact which parents were made aware of. After ten minutes of free play, the experimenter returned to the main room, sat down on the blanket, and asked questions from the IBQ-R for another ten minutes; this constituted the PCI-Q part of the procedure. Afterwards, the baby was again presented with the same animation, saliva samples were collected, and the baby then participated in the table top and eye-tracking tasks. At the end of the visit, the parent filled in the Parent-Infant Caregiving Scale and Social Touch Questionnaire. They were also given instructions for the Touch Diary and were informed that completing all seven days of the diary would qualify them to participate in a draw to win a 50 euro Amazon voucher. The links to each day entry of the Touch Diary were sent to the parents every day for seven consecutive days, with the first one being sent on midnight the day following the visit in the lab, and the next ones following every 24 hours.

3.2.4 Analytical Approach

I start by characterizing the range of normal variation in the behaviours of interest, across measures, as well as their associations with infant age. I also compare PCI-Q and PCI-FP. I then go on to investigate to which extent measures of caregiver touch agree with each other. I focus on associations between putative equivalent measures (e.g. stroking in Touch Diary and the PICTS, holding in the Touch Diary and the PICTS, and Total touch in PICTS, PCI-FP and PCI-Q). I go on to perform a Principal Component Analysis on all collected measures of caregiving behaviours.

Finally, I qualitatively compare practical aspects of using a questionnaire, a diary and parent-child interaction- derived measures.

The descriptive statistics, Pearson and Spearman correlations and the Wilcoxon signed-rank tests were performed using SPSS (PASW, IBM, version 24.0), while the PCA and data visualization was performed in R (version 3.6.0.; R Core Team, 2019), using FactoMineR (Lê et al., 2008) and missMDA (Josse & Husson, 2016) packages.

3.3. Results

3.3.1. Touch Diary characteristics

Forty-two caregivers (out of seventy one) completed all seven days of the Touch Diary, a completion rate of 59%. An additional four parents completed six out of seven days, and their scores were also included in the analyses, resulting in a final completion rate of 65%. This completion rate is comparable to that in other studies employing this approach (e.g. Nicholl, 2010).

Descriptive statistics can be found in Table 3.1. While the amount of time spent talking is normally distributed in our sample, this is not the case for stroking and cuddling (see the Shapiro-Wilk tests in Table 3.1). I did not find significant associations between infant age and talking (r_s = -0.01, n = 46, p = 0.98), stroking (r_s = -0.15, n = 46, p = 0.31), or holding (r_s = -0.25, n = 46, p = 0.10).

3.3.2 Parent-Infant Caregiving Touch Scale characteristics

Sixty-eight parents provided PICTS scores, with data from three parents missing due to parents not completing the questionnaire (2 participants) or experimenter error (1 participant). The Cronbach's α value for the total score in our sample was 0.71, which can be considered appropriate (A. Field et al., 2012). The mean value of the overall PICTS score was 54 (N = 68, minimum = 39, maximum = 65, SD = 5). Table 3.1. shows descriptive statistics for the total PICTS score and subscales. Please note that the subscales Holding, Affective Communication, and Proximity are non-normally distributed. See Figure 3.1. for histograms showing the distributions of scores.

Table 3.1. Descriptive statistics for Touch Diary, PICTS and its subscales, and STQ

	Mean score	Standard Deviation	Minimum	Maximum	Shapiro-Wilk (Test of Normality)		
					Statistic	df	Sig.
Diary - Talking (N = 46)	275 minutes	110 minutes	24 minutes	489 minutes	0.97	48	0.35
Diary - Holding(N = 46)	215 minutes	126 minutes	42 minutes	655 minutes	0.87	48	<0.001
Diary - Stroking (N = 46)	127 minutes	70 minutes	13 minutes	307 minutes	0.94	48	0.024
PICTS - Total (N = 68)	54	5	39	65	0.98	68	0.32
PICTS - Stroking	15	3	8	20	0.98	68	0.27
PICTS - Holding	19	2	13	23	0.96	68	0.02
PICTS - Affective Communication	26	2	20	30	0.95	68	0.01
PICTS - Proximity	6	2	2	10	0.96	68	0.04
STQ (N = 70)	28	9	7	48	0.98	70	0.52

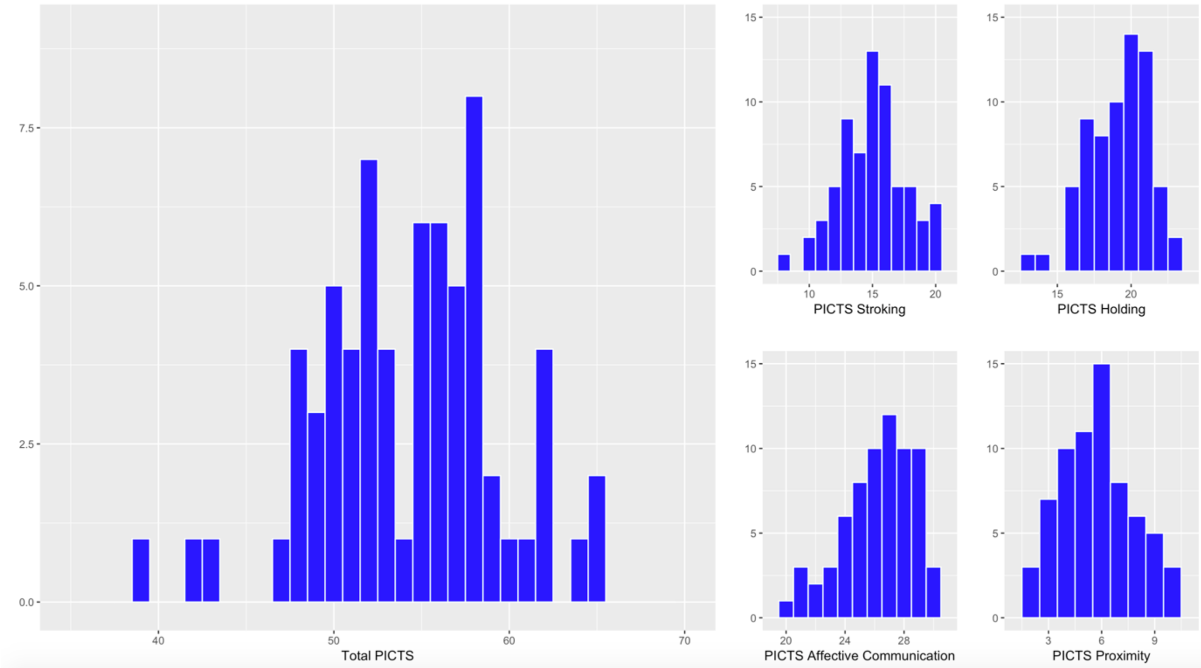

Figure 3.1. Distributions of the total PICTS score, and the subscale scores

I did not find significant associations between infant age and either the Total PICTS score (r_s = -0.11, n = 68, p = 0.37), Stroking (r_s = -0.07, n = 68, p = 0.57), Holding (r_s = -0.01, n = 68, p = 0.99), or Affective Communication (r_s = -0.01, n = 68, p = 0.99). Proximity showed a trend towards a negative correlation with infant age (r_s = -0.24, n = 68, $p < 0.05$), but it did not reach statistical significance after correcting for multiple comparisons (p = 0.005 significance threshold Bonferroni correction for multiple comparisons).

3.3.3. Social Touch Questionnaire characteristics

All but one participant provided STQ scores. The STQ score is normally distributed in the present sample. The Cronbach's α value was 0.75, indicating appropriate reliability (Field et al., 2012). I did not find an association between the STQ score and infant age ($r_s = 0.17$, $n = 70$, $p = 0.17$). More detailed descriptive statistics can be seen in Table 3.1.

3.3.4. Parent – Child Interaction characteristics

Characteristics of the different categories of touch, as coded from the Parent Child Interaction – Free Play and Parent Child Interaction – Questionnaire are depicted in Table 3.2. Descriptive statistics on touching behaviours in a playful (PCI-FP) and functional (PCI-Q) context, and Wilcoxon signed rank tests between median durations of touching behaviours in those two contexts are presented in Table 3.2. Histograms depicting duration distributions of some of the touch categories during PCI-FP and PCI-Q can be found in Supplementary Material. Our findings suggest that caregiver touch during a free play, infant-focused situation differs both quantitatively and qualitatively from caregiver touch in a situation where the caregiver's attention is not focused on the infant.

I found a significant negative correlation between PCI-FP Total Touch ($r_s = -0.40$, $n = 71$, $p = 0.001$) and infant age. PCI-Q Total Touch showed a trend towards a negative correlation with infant age ($r_s = -0.28$, $n = 68$, $p = 0.02$) which did not reach the Bonferroni-corrected significance level of 0.005. There was a trend towards a negative correlation between stroking and age during free play ($r_s = -0.33$, $n = 67$, $p = 0.006$), but not during a non-playful interaction ($r_s = 0.09$, $n = 69$, $p = 0.481$).

Table 3.2. Descriptive statistics for touch behaviour categories in PCI-FP and PCI-Q (data from both age groups pooled together). Categories were coded over a period of 300 seconds (5 minutes).

Touching behaviour category	PCI-FP Mean [s]	PCI-FP Standard Deviation [s]	Category did not occur	PCI-Q Mean [s]	PCI-Q Standard Deviation [s]	Category did not occur)	Wilcoxon signed rank-test PCI-FP vs. PCI-Q
total touch	151.1	84.5	0 (0%)	121.3	100.6	1 (1%)	Z = -2.2, p = .028
hug/hold/cradle	55.7	55.4	6 (9%)	96.7	107.6	10 (15%)	Z = -2.5, p = .013
static	30.4	30.5	7 (11%)	19	29.4	8 (12%)	Z = -3.0, p = .003
tickle	10.2	12.4	10 (15%)	0.6	1.4	48 (71%)	Z = -6.0, p < .001
stroke/caress	5.7	6.7	15 (23%)	6.9	11.1	15 (22%)	Z = -0.1, p = .92
moving limbs/body	37.6	36.5	11 (17%)	7.9	8.7	15 (22%)	Z = -5.3, p < .001
kiss, pat	8.2	17.4	13 (20%)	1.1	2.1	36 (53%)	Z = -5.8, p < .001
touch with objects	6.8	13.3	23 (35%)	9.2	13.7	22 (32%)	Z = -1.3, p = .19
rocking	10.8	22.5	42 (64%)	23.6	56.2	49 (72%)	Z = -1.4, p = .18
games/routines played on body	1.2	3.6	57 (86%)	0	0	68 (100%)	Z = -2.6, p = .008
massage	0.1	0.5	63 (95%)	0.8	2.2	57 (84%)	Z = -2.5, p = .012

3.3.5. Associations between measures of equivalent behaviours

Pearson and (where the variables did not meet the normality criterium - see Table 3.1.) Spearman correlations were calculated to investigate the consistency between measures supposed to capture equivalent behaviours, and relationships between self-reported and observed measures of caregiver touch: stroking in Touch Diary and the PICTS, holding in the Touch Diary and the PICTS, and Total touch in PICTS, PCI-FP and PCI-Q. The significance level was Bonferroni corrected for multiple comparisons with the resulting threshold of $p = 0.004$.

I found that stroking reported in the Touch Diary was positively correlated with the Stroking factor of PICTS ($r_s = .45$, $n = 44$, $p = .002$). No other relationships between variables supposed to reflect particular behaviours reached statistical significance. However, I found the total PICTS score to be correlated with total touch in PCI-FP ($r_s = .39$, $n = 68$, $p = .001$).

These results indicate some consistency between the self-reported measures of parental stroking, and confirm the external validity of the PICTS scale for the first time, showing that its scores map onto caregiver behaviour as observed in the lab.

Correlations between all relevant measures are shown in Table 3.3.

Table 3.3. Bivariate correlations (Spearman's Rho in light grey, Pearson's in white) between measures. P-values are not corrected for multiple comparisons.

		PCI-FP total	PCI-Q total	Diary - Holding	Diary - Stroking	PICTS - total	PICTS - Stroking	PICTS - Holding
PCI-FP total	Correlation Coefficient		.269*	0.040	0.094	.410**	.250*	.329**
	Sig (2-tailed)		0.027	0.790	0.535	0.001	0.040	0.006
	N		68	46	46	68	68	68
PCI-Q total	Correlation Coefficient			-0.131	-0.140	0.011	-0.029	-0.102
	Sig (2-tailed)			0.398	0.366	0.932	0.819	0.419
	N			44	44	65	65	65
Diary - Holding	Correlation Coefficient					.365*		0.206
	Sig (2-tailed)					0.015		0.179
	N					44		44
Diary - Stroking	Correlation Coefficient						.416**	
	Sig (2-tailed)						0.005	
	N						44	

3.3.6. Dimensional data structure

Principal component analysis (PCA) was conducted as a part of an exploratory investigation into the overall dimensional structure of the data. I aimed to understand the dimensional structure underlying our collection of measures, specifically, whether I could observe a common underlying factor emerging from all our measures. Variables violating the 'no significant outliers' assumption of PCA were excluded from the analyses, leaving Stroking PICTS, Holding PICTS, Affective Communication PICTS, Proximity PICTS, STQ, total duration of touch during PCI-FP, and PCI-Q, and diary measures of stroking and talking. In order to correct for missing data (which was quite a high proportion in the diary measures – 35%), I used the MissMDA R package to perform multiple imputation with the iterative PCA method (Josse & Husson, 2016). This method of handling missing data has been found to be optimal for performing PCA (Dray & Josse, 2015). Data from both age groups was pooled in order to fulfil the sampling adequacy criterium of PCA (5 – 10 cases per variable). The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis KMO = .67, which is above the acceptable limit of .5 (Field, Miles, & Field, 2012; p. 770). Bartlett's test of sphericity, χ^2 (36) = 176.523, p < .001 indicated that correlations between items were sufficiently large for PCA. Analysis of the scree plot suggested that two components should be retained. In combination, these two components explained 53.41% of the variance. Figure 3.2. shows a visualisation of unrotated PCA results with added uncertainties generated by the multiple imputation, and factor loadings can be found in Table 3.4.

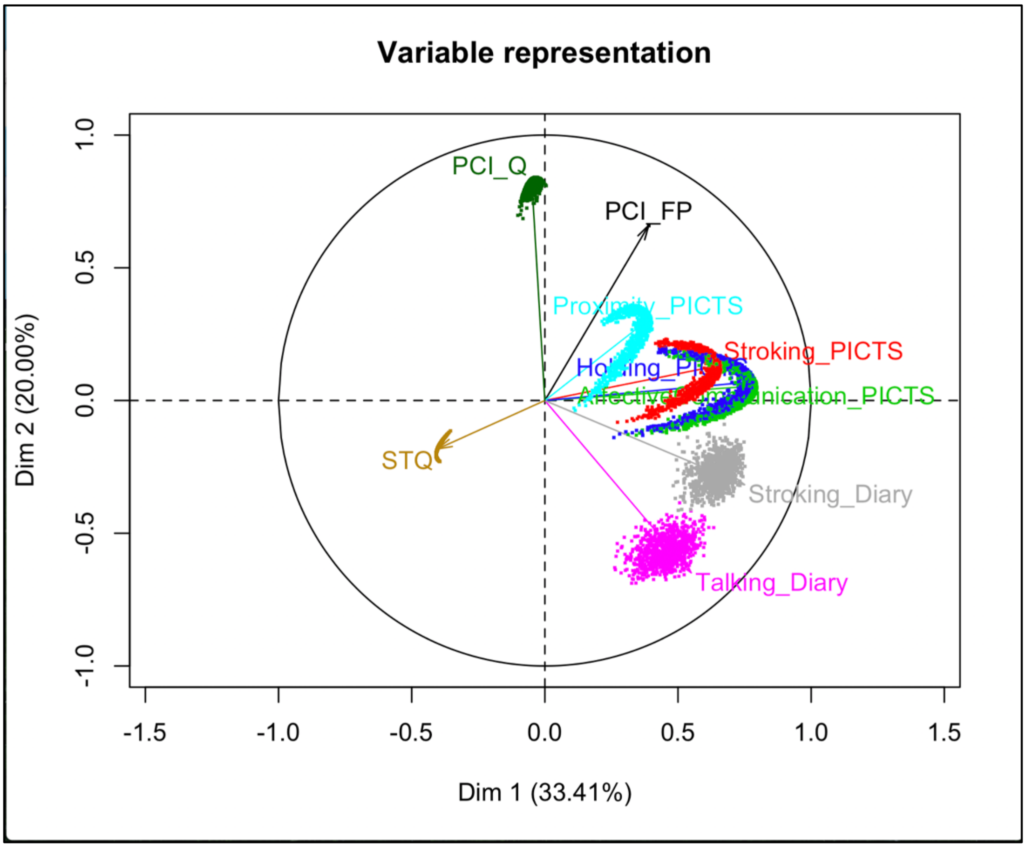

Figure 3.2. Variable representation in the PCA two-dimensional space (unrotated), with visualised uncertainties associated with imputation of missing values. The ellipses and clouds of dots represent overlapped outcomes of the PCA after 1000 imputation simulations.

Table 3.4. Factor loadings of the PCA

	Factor loadings	
Measure	**Dimension 1**	**Dimension 2**
Affective Communication - PICTS	0.79	0.05
Holding - PICTS	0.78	0.07
Stroking - PICTS	0.66	0.13
Proximity - PICTS	0.39	0.30
Stroking - Diary	0.75	-0.32
Talking - Diary	0.55	-0.65
STQ	-0.40	-0.18
PCI - FP	0.39	0.66
PCI - Q	-0.05	0.83
% of variance	33.41	20.00

The items that load on the two dimensions suggest that Dimension 1 is more associated with self-reported measures of caregiving behaviours, while Dimension 2 represents directly observed caregiver touch. This is compatible with the idea that Dimension 1 is more associated with what has been called "faking good" (Field, 2019), while Dimension 2 is a more accurate account of caregiver behaviour patterns. PCI-FP loads positively onto both dimensions, which would indicate that while it is a direct observation, there is also an element of the caregiver potentially being hyper-conscious of their behaviour, wanting to perform. However, it may also be the case that when reporting their touching behaviours, caregivers are better at recalling those interactions in which they were focused on the infant, which is why self-report measures may be more biased towards touch measured during play rather than capturing touch throughout daily activities.

One interesting feature of the results is the negative loadings of the Diary measures of talking and stroking onto Dimension 2, which speaks in favour of the playful vs. non-playful interpretation of the two dimensions. In this interpretation, Dimension 1 reflects caregiver behaviour in free-play, infant-focused interactions, while Dimension 2 is associated with touch in everyday situations in moments when caregiver attention is not focused on the baby. In such situations, talking to and stroking the baby would not necessarily occur. However, given the amount of missing data and the uncertainties associated with the Touch Diary measures (see Figure 3.2.), one has to be cautious when drawing conclusions based on these measures.

Another possible interpretation of the two dimensions is that Dimension 1 captures affective, while Dimension 2 – non-affective caregiver touch. This idea is supported by the significant loadings of the self-reported measures of affective touch, as well as touch employed during a playful interaction on Dimension 1. In this scenario, Dimension 2 would represent touch which serves a functional purpose, e.g. securing the infant's position, keeping the infant safe.

STQ, a measure of anxiety and discomfort associated with social touch, loads negatively onto both dimensions, albeit the loading onto Dimension 1 is larger. This indicates that parental attitudes and affects towards social touch are, as predicted, associated with caregiving behaviours, but more so in case of self-reported touch and touch occurring in playful/infant-focused interactions.

3.4. Discussion

Researchers wanting to investigate the relationship between touch and infant development face a difficult challenge of choosing the right measure(s) to capture the dimensions of touch they are interested in. By employing three different measures of caregiver touch in one study, one-off questionnaires, a diary and objective measures captured during parent-child interaction, I were able to not only describe the natural variation in various aspects of caregiving behaviours, but also show how those measures relate to each other.

I observed significant variation across behaviours of interest, with a number of variable distributions being normal. This observation was particularly informative with regard to the PICTS questionnaire measure (Koukounari et al., 2015), as it could have been subject to a ceiling effect, with the possibility of parents consistently reporting high levels of touching behaviours in efforts to come across as good caregivers. I did however find the total score and the Stroking subscale score to be normally distributed in our sample.

An important feature of our study was observing touch both during play, as most previous studies have, and in a situation in which parents may not be particularly focused on or aware of their typical caregiving behaviours. The latter condition differed from the former in two important ways: the interaction was not infant-focused, and there was ambiguity as to whether or not parents' behaviour was being measured. As predicted, I observed quantitative and qualitative differences in parental touching behaviours between these contexts. Parents generally touched their children less when talking to the experimenter than during free play. It is important to note though that, although total duration of touch was smaller in PCI-Q, the spread was larger, suggesting that this measure captures more variance. The nature of touch behaviours varied, with more holding during PCI-Q but more playful touch (tickling, kissing) during PCI-FP. Interestingly, no differences were found in the time spent stroking the child. In general, I found that parents used relatively little stroking during PCI. This finding is consistent with what was reported in other studies using observed measures of touch (Jean & Stack, 2009; Mantis et al., 2019). Despite the documented benefits of this type of tactile stimulation (Pickles et al., 2017; Van Puyvelde et al., 2019), and the enhanced focus on investigating its mechanisms in early development (Gliga, Farroni & Cascio, 2019), stroking may occur relatively rarely, or mostly in specific contexts (e.g. feeding or rest). Thus, stroking may be better captured by parental self-reports, which reflect on touch across daily activities. I indeed found a good degree of agreement between the PICTS stroking subscale and stroking reported in the diary.

With regard to infant age, I observed that the older the babies were, the shorter were the observed total durations of caregiver touch during parent-child interactions. Jean et al. (2009) found a similar effect in a longitudinal study with infants aged 1, 3 and 5 and a half months. This observation comes as little surprise, considering how a lot of caregiver-infant physical contact serves the purpose of moving or securing the position of an infant whose motor skills do not yet allow them to do so themselves (Little et al., 2019), and gross motor skills develop rapidly around the time infants turn one year old (Adolph & Robinson, 2015). What is more interesting, is that the self-report measures of caregiver touch in our study did not show such associations with infant age. While this finding could indicate that self-reported touch is biased towards 'faking good', the fact that questionnaire scores were correlated with parental behaviour observed in the lab speaks against this interpretation. It is more likely that the self-reported estimates of touch provide information on beliefs which are fairly stable across infant development. This is a first indication that self-report measures also capture individual differences in parental tendencies and attitudes associated with their caregiving practices.

When comparing touch estimates across measures, I found the total PICTS scores to be moderately correlated with the duration of touch in parent-infant interaction, demonstrating that the PICTS scores map onto real-life caregiver behaviour. Considering that the PICTS is a relatively short, uncomplicated questionnaire filled out by the parent at a single time point, this finding further confirms the usefulness of this psychometric tool. Our analysis of the dimensional structure of our data also showed that touch during free play was more positively related to parental self-reported touch than touch in the functional context, with the latter forming an independent dimension. All this evidence combined suggests that the self-report and free-play-based measures may not capture the entire spectrum of caregiver touching behaviours. In particular, our findings suggest that the PICTS is biased towards reporting on touch during periods of time in which the parent is focussed on interacting with the child.

An ideal measure would describe parental touch across a variety of contexts, yielding full-scale estimates similar to those in animal studies. Diaries, in theory, have the potential of fulfilling this criterium, considering the time-span they cover and their straightforward descriptiveness. However, in the present study I found little added value of the diary measure. The dimensional structure of our data revealed that the diary-based estimates were closer to the questionnaire-based estimates than to the touch observed during parent-child interaction. Moreover, our diary measure was associated with a large proportion of missing data. Even though I tried to make it easy to use, with a slider-scale and smartphone-friendly design, filling it out daily was likely still a cumbersome task for parents of infants.

One of the objectives of our study was to compare the practical aspects of existing caregiver touch measures. Table 3.5. provides a brief overview of our insights into the psychometric aspects as well as the time costs for both the parent and the researcher, and the amount of missing data associated with each measure. This overview is largely based on our subjective observations, and it is possible that in other samples or with slightly modified methods these features would look different – our aim was to draw attention to the advantages and disadvantages I experienced.

Table 3.5. Comparison of psychometric and practical aspects of each measure of caregiver touch

Measure	What is measured	Correlates with infant age	Correlates with other measures	How time consuming for the parent	How time consuming for the researcher	Amount of missing data
PICTS-adapted	touch in infant-focused/playful interactions	no	yes – positively with PCI-FP and Diary	low	low	low
Touch Diary	touch in infant-focused/playful interactions	no	yes – positively with PICTS	high	moderate	high
PCI-FP	touch in everyday situations, playful and non-playful	yes - negatively	yes – positively with PICTS and a trend towards a positive correlation with PCI-Q	moderate	high	low
PCI-Q	touch in everyday non-playful interactions	no (trend towards a negative correlation)	trend towards a positive correlation with PCI-FP)	moderate	high	low

In conclusion, I find moderate to low agreement between measures of caregiver touch, in infancy. A brief questionnaire, the PICTS, seems to capture touch during particular daily activities, when caregiver's attention is directed to the child, but may provide a more veridical estimate of particular types of touch, such as stroking. Given the key role given to this type of touch in developmental literature, this may explain why the PICTS associates with various developmental variables (e.g. Pickles et al., 2017). For a broader depiction of caregiver touching behaviours, researchers ideally should record parent child interaction in a variety of contexts. This may be true for capturing other types of interaction, not only touch. Just as is now possible to record verbal interaction continuously during the day, to validate lab-based or questionnaire measures (Canault et al., 2016), in the future smart suits (Yao et al., 2019; Zhu et al., 2015) may automatically register physical contact. Efforts to automate the video-coding process (e.g. Chen et al., 2016) could decrease the workload on the researchers and make it feasible to extend the period of time during which touch is directly observed and characterised.

In the following chapters (Chapters 4 to 7), I will use the two dimensions yielded by the PCA analysis as the main predictors of infant outcomes. I favour the interpretation of the two dimensions as representing self-reported and observed caregiver touch, and that is how I will refer to them in the chapters that follow. However, it has to be noted that at the same time, the Self-reported dimension likely captures affective touch better, while the Observed touch dimension might to a large extent represent non-affective, functional types of touch, consistent with the items loading onto the respective dimensions. Where I have hypotheses about short-term effects of affective touch used during the session, I will also investigate the associations between the amounts of affective types of caregiver touch, as coded from the interaction videos, and measures of infant hormonal response and exploratory behaviour. In the next chapter, I now turn to exploring the relation between caregiver touch and infant hormonal response.

Chapter 4

Caregiver touch and infant hormonal response

4.1. Introduction

One line of research into the impact of caregiver touch on infant development has focused on its effects on infant hormonal responses. Two hormones have been particularly relevant to investigate the links between touch and exploratory behaviour – oxytocin and cortisol. The associations between touch and cortisol were described in Chapter 1. In this chapter, I present a short review of the literature on the associations between touch and oxytocin, with a special focus on early development, as well as the results of our study investigating the relationship between naturally occurring variations in caregiver touch and infant cortisol and oxytocin.

4.1.1. Methodological considerations

Scientists investigating the function of oxytocin in human participants have employed a variety of approaches. One approach has been to look into the associations between oxytocin receptor gene polymorphisms and behaviour (Apter-Levy et al., 2013; Truzzi et al., 2018). However, although these investigations are informative with regard to the correlates of one's genetic makeup, they tell us little about the functioning of the oxytocin system and its physiological impacts. The three most common approaches that allow such investigations are: (1) measuring circulating oxytocin levels in blood (Feldman, Gordon, & Zagoory-Sharon, 2010; Weber et al., 2017, 2018), saliva (Gordon et al., 2010; Vittner et al., 2017) and, less frequently, urine (Hardin et al., 2020; Weber et al., 2017)(2) assessing DNA methylation of conserved regulatory sites within the oxytocin receptor gene (mOXTR) (Krol, Moulder, et al., 2019; Moore et al., 2017) and, (3) examining the effects of intranasally administered oxytocin (Fragkaki et al., 2020; Gamer & Büchel, 2012). Each of these approaches is briefly discussed below, with a special focus on their feasibility with infant participants.

4.1.1.1. Measuring oxytocin in blood, saliva and urine

A common approach to measuring oxytocin is through collecting samples of blood, saliva or urine, and then measuring the oxytocin concentrations in them. Concerns have been raised about the diversity and validity of the various techniques (including radioimmunoassay, enzyme immunoassay, etc.) employed to assess oxytocin levels in these fluids (see McCullough et al., 2013 for a critical review). However, the discrepancies produced by different methods do not necessarily imply that some methods are valid while others are not – rather, they pick up on different states in which the oxytocin molecule can exist (MacLean et al., 2019). Though it is not yet fully understood how oxytocin makes its way from the central nervous system into the periphery, a recent meta-analysis of oxytocin studies has revealed a clear and significant association between central and peripheral oxytocin. However, this association was only present in experimental conditions (e.g. after exposure to a stressor) and not at baseline (Valstad et al., 2017). Thus, Valstad and colleagues (2017) conclude that peripheral oxytocin measures should not be used to make inferences on central oxytocin concentrations under baseline conditions.

With regards to developmental populations, Nishizato et al (2017) reported a decrease in basal salivary oxytocin levels between the ages of 5 months to 7.5 years, which was accompanied by a decrease in attention to social cues, and an increase in attention to non-social cues. The authors hypothesised that the decline in oxytocin levels could be caused by a reduction in interactions between the child and their caregiver, as the child gets older. However, their data seem to suggest a decrease in variability of oxytocin levels, rather than a continuous decrease of oxytocin levels with age (see Figure 4.1.). In particular, within the 6 to 13 months range (which is the age range in the current study), juding based on the scatterplot depicted in Figure 4.1., it is unclear if a decrease in salivary oxytocin is to be expected.

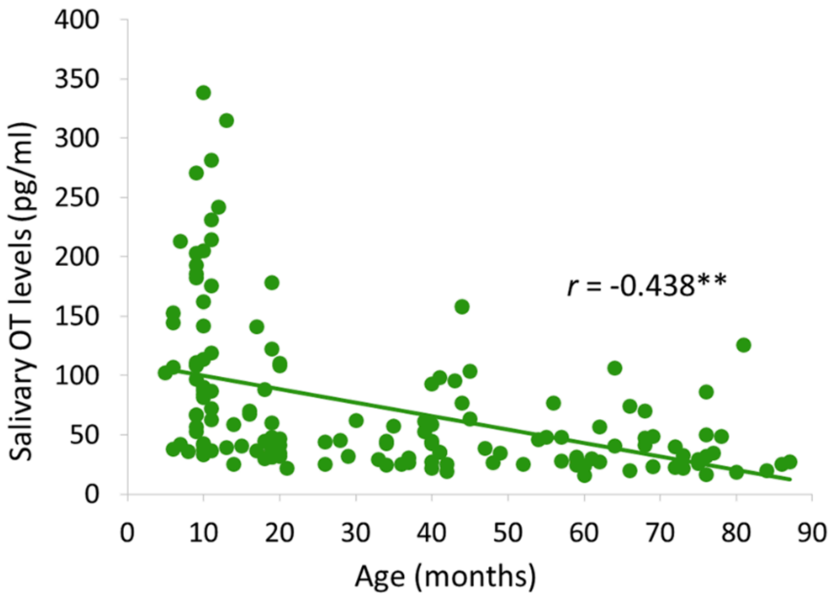

Figure 4.1. Relationship between age and salivary oxytocin (OT) levels. The vertical axis indicates salivary OT levels [pg/ml], whereas the horizontal axis indicates age [months]. **p<0.01. From Nishizato et al. (2017)

It has also been argued that measuring oxytocin in saliva may be superior to measuring it in blood, as oxytocin in blood tends to bind to large proteins, leading to challenges for detection (MacLean et al., 2019). Consequently, measuring oxytocin in saliva has been the most common approach in recent years and has the added benefit of being the least invasive option as well (Kommers et al., 2018; Schladt et al., 2017; Vittner et al., 2019).

Another potentially infant-friendly method is measuring oxytocin in urine. This is the least used method and possibly the most controversial because of doubts over its reliability. In preterm babies, there is no agreement between plasma and urine measures of oxytocin; while plasma oxytocin decreases with age, urine oxytocin does not, and the two are uncorrelated (Weber et al., 2017). Still, it may just be that urine-based measures represent a different state of the oxytocin molecule than plasma-based measures do, and depending on the chosen detection method, only free, or also bound oxytocin can be detected (MacLean et al., 2019). Some have employed urine-based oxytocin measures and observed seemingly meaningful results, like moderate to large (although not significant) increases in oxytocin after skin-to-skin contact (Hardin et al., 2020). Nonetheless, sampling urine is not as time-flexible as sampling saliva (especially with infant participants, as they cannot control their bladder and urination timings are hard to predict) and when time-locked measurements are needed, this may not be an optimal approach.

Even after collecting a sample of the chosen bodily fluid, many steps are involved in the assay process and various ways of handling the samples can affect the results. The discussion of the intricacies of the assay process goes beyond the scope of this thesis, but there are papers which discuss these topics in detail (Jurek & Neumann, 2018; McCullough et al., 2013).

To conclude, it seems that with babies, measuring oxytocin in saliva is the easiest and most flexible method, and it can provide interesting information, even if it is just a part of the full picture. Based on the research described above, I chose to use the salivary oxytocin measure in the current study.

4.1.1.2. Epigenetic modifications – OXTRm

Another approach to assessing individual differences in the oxytocin system is through investigating the epigenetic modification of oxytocin receptor genes, also known as DNA methylation of the oxytocin receptor gene – OXTRm (e.g. Krol, Moulder, et al., 2019; Krol, Puglia, et al., 2019; Moore et al., 2017). Environmental factors, such as parental caregiving, can influence gene expression through methylation of certain gene regions (Jaenisch & Bird, 2003). Increased methylation of a region in the human oxytocin receptor gene (OXTR) is associated with reduced expression of OXTR (Krol, Puglia, et al., 2019; Kusui et al., 2001). Thus, epigenetics provides a developmental model for how caregiving factors can affect infant development.

OXTRm can be assessed with the use of samples which are typically used to isolate DNA, including blood and saliva – and unlike salivary and blood oxytocin, salivary and blood OXTRm are highly correlated (Krol, Puglia, et al., 2019). However, OXTRm measures only offer insights into long-term correlates of caregiving factors, and thus are not appropriate for examining short-term (immediate) effects of external factors, which was one of the goals of the present study.

4.1.1.3. Intranasal administration of oxytocin

Intranasal oxytocin administration has heavily influenced theories regarding the causal role of oxytocin in humans. Numerous studies have investigated the effects of synthetic, intranasally administered oxytocin, usually on social domains of behaviour (Domes et al., 2007; Gamer & Büchel, 2012; Venta et al., 2017). Even though it is not exactly clear how intranasally administered oxytocin reaches central nervous system, effects beyond placebo are observable (Lin et al., 2014). Moreover, it has been documented that administering oxytocin intranasally results in elevated oxytocin levels in saliva (van IJzendoorn et al., 2012). As the elevated levels of oxytocin in saliva were observable even seven hours after intranasal oxytocin administration, the authors of the study suggest that the synthetic oxytocin reached the brain because peripheral mechanisms (such as the movement of mucus) were unlikely to account for such long-lasting effects; rather, a mechanism similar to sublingual of transdermal drug administration could have been at play (Huffmeijer et al., 2012; van IJzendoorn et al., 2012). Although not commonly used with developmental populations, intranasal oxytocin administration has previously been employed in studies with adolescents (Venta et al., 2017) and children (Dadds et al., 2014). However, no studies have used this method with infants – most likely because of the more stringent ethical precautions characteristic of human infant studies[10].

[10] However, see the study by Arias del Razo et al. (2020) with 12- to 18-month-old titi monkeys, in which administering intranasal oxytocin caused a modest increase in social behaviour.

4.1.2. Oxytocin and touch in human infants

Just how little was known about oxytocin in early human development until recently is well-illustrated by the fact that a widely-cited 2015 review paper titled "*Developmental perspectives on oxytocin and vasopressin*" by Elizabeth Hammock (Hammock, 2015) cites a total of five research papers reporting any type of oxytocin-related data from human children, two of which concern infants (Feldman, Gordon, & Zagoory-Sharon, 2010; Weisman et al., 2012). Only one of the infant-focused papers addresses the relationship between touch and oxytocin, and does so indirectly (Feldman, Gordon, & Zagoory-Sharon, 2010). A construct called "affect synchrony", the proportion of time a parent and child coordinated their positive engagement (which included touching behaviours such as hugging, kissing, stroking in response to infant positive affect) in a free play session observed in the lab, was found to be positively associated with infant salivary OT levels fifteen minutes after the session (Feldman, Gordon, & Zagoory-Sharon, 2010). While this result supports the predictions drawn from rodent studies, more recent research paints a more complex picture.

Indeed, several studies published in recent years have more explicitly tackled the question of whether tactile stimulation leads to oxytocin release in human infants (Hardin et al., 2020; Kommers et al., 2018; Vittner et al., 2017, 2019). Some researchers have investigated the relationships between infant oxytocin and various qualities of caregiving behaviour, like "maternal engagement" (Vittner et al., 2019) and "maternal affect attunement" (Markova, 2019), and observational qualities like engagement in social games with the child during a naturalistic interaction (Markova, 2018). Although these investigations have not explicitly included touching behaviours as predictors of infant outcomes – an omission some would point out as untenable, considering how touch is conceptualised as essential within maternal attachment and sensitivity research (Botero et al., 2019) – they nevertheless provide some indirect insights into the topic of touch and oxytocin in infancy. Additionally, recent years have seen multiple efforts to link early caregiving qualities, including touching behaviours, to infant DNA methylation (see Provenzi et al., 2020 for a review), with the OXTR gene being one of the target genes (Krol, Moulder, et al., 2019; Moore et al., 2017).

A review-summary of studies which have investigated caregiving factors' associations with infant OT can be found in Table 4.1.

Table 4.1. Review of studies investigating associations between parental caregiving qualities or caregiving-related interventions and infant oxytocin

First Author	Year	Participants	Sample Size	Caregiving Quality/Intervention	Measure of Oxytocin	Outcome
Feldman	2010	4-6-month-olds (full-term)	n = 55	parental "affect synchrony"	salivary	↑OT (correlation)
Weisman	2012	5-month-olds (full-term)	n = 35	parental touch and "social reciprocity" (indirectly - after OT administration to fathers)	salivary	↑OT(correlation)
Vittner	2017	premature newborns	n = 28	Kangaroo Care intervention	salivary	↑OT (experimental)
Moore	2017	5-week-olds and 4.5-year-olds (full-term; longitudinal)	n = 94	tactile contact	OXTRm	no associations (correlation)
Fujiwara	2018	3-10-month-olds (full-term)	n = 90	parental care and overprotection	salivary	no associations (correlation)
Kommers	2018	premature newborns	n = 22	Kangaroo Care intervention	salivary	↓OT (experimental)
Markova	2018	4-month-olds (full-term)	n = 43	time spent playing social games	salivary	↓OT (correlation)
Vittner	2019	premature newborns	n = 28	maternal engagement	salivary	↓OT (experimental)
Markova	2019	4-month-olds (full-term)	n = 43	maternal "affect attunement"	salivary	high affect attunement → OT positively associated with infant social engagement (direct relationship not tested; correlation)
Krol	2019	5- and 18-month olds (full-term; longitudinal)	n = 101	maternal engagement	OXTRm	↓OXTRm (correlation)
Hardin	2020	newborns and 3-month-olds (full-term; longitudinal)	n = 17	Kangaroo Care intervention	urine	↑OT (experimental)

NOTE: OXTRm = DNA methylation of conserved regulatory sites of the oxytocin receptor gene

As can be seen in Table 4.1, literature on the topic is rather scarce and results are far from conclusive. It is important to point out that the reviewed studies vary not only in the caregiving qualities or caregiving-related interventions investigated (and how directly they captured parental touch), but also in infant age, whether or not the infants were born prematurely, the timeline of the studied associations (immediate or longitudinal effects, as well as the time-window between measurements) and measures of oxytocin activity (salivary, urine or OXTR methylation).

Considering all these differences, it is hard to compare studies directly or to perform a meaningful meta-analysis; nevertheless, I will try to give a general overview of the picture that emerges from the research so far.

The three studies that manipulated touch did so by looking at infant outcomes of Kangaroo Care (KC, or, skin-to-skin contact; SSC), and only one of them (Hardin et al., 2020) had full-term infants as participants. The two studies with premature infants reported contradictory results: Vittner et al. (2017) found that infant salivary oxytocin levels increased during skin-to-skin contact compared to baseline, whereas Kommers et al. (2018) found the opposite. Though the Kangaroo Care procedures in both studies were virtually identical, Vittner et al. (2017) measured the oxytocin response during two skin-to-skin sessions (one with the mother and one with the father), whereas Kommers et al. (2018) did so over five consecutive days of skin-to-skin contact, pooling saliva from multiple sessions to yield a single estimate – a technique they deemed relatively unobtrusive to preterm infants in their previous study (Kommers et al., 2017). Moreover, though the sample sizes in both studies were comparable (n = 28 vs. n = 22 infants), Kommers et al. (2018) specifically recruited twin pairs in their study, in order to "minimise variability", potentially introducing a different bias into the dataset by increasing the correlations that exisits between pairs of infants baseline oxytocin levels. What is more, twins have different tactile experiences in the womb, and thus their response to touch may not be representative of all infants. Another small, but perhaps not negligable difference between the two studies was that Vittner et al. (2017) collected the saliva sample 50 minutes into KC, while Kommers et al. (2018) did it after at least 30 minutes of KC had elapsed. It is possible that the oxytocin response to prolonged skin-to-skin contact has a timecourse which would explain the discrepancies between the two study results, yet a drop in oxytocin during touch with regard to baseline was a surprising finding, even to the authors of the study (Kommers et al., 2018).

Recently, Hardin et al. (2020) hypothesised that Kangaroo Care would lead to an increase in oxytocin levels in full-term babies. Instead of comparing infant oxytocin levels during KC to those at baseline, they employed a between-subjects design: some mothers (n = 16) were taught KC procedures during the neonatal period and instructed to perform them for 6 consecutive weeks, 1 hour per day, while others (n = 17) were given infant feeding pillows and journals in which they were asked to record infant feedings for an equivalent period of time. Urine oxytocin was measured in newborns, before the KC intervention, and then, after the intervention, in 3-month-olds. A large effect size pointing towards an increase of oxytocin in the KC group (relative to the control group) was found, but the difference did not reach statistical significance; it is worth mentioning that the study was severely underpowered, with only nine subjects in the KC and eight in the control group providing oxytocin data. As such, the authors' claims that the study provided evidence for KC-induced increases in oxytocin levels in full-term infants have to be treated with caution. Yet, Hardin et al. (2020) remains the only existing study explicitly investigating the effects of a touch-based intervention on oxytocin levels in full-term infants.

The only study to have examined the long-term effects (beyond the first year of life) of tactile contact provided in the first months of life on infant oxytocin-related activity did it through looking at associations between maternal self-reported tactile contact with the infant and DNA methylation of the oxytocin receptor gene (OXTRm) in the child 4-5 years later (Moore et al., 2017). In this study, over a thousand mothers of full-term infants were asked to fill out a diary reporting physical contact durations with their babies over a period of at least three days. Based on the data from these diaries, employing an approach drawn from rodent studies (e.g. Francis et al., 1999), two groups of mothers were identified: those employing low levels of contact (contact time per day one standard deviation below the mean for daily physical contact time; n=39) and high levels of contact (contact time per day one standard deviation above the mean for daily physical contact time; n=55). The low and high contact groups differed by almost 9 hours of self-reported tactile contact per day, on average. Despite the authors' hypotheses, no significant differences between these two groups in OXTRm at 4-5 years were found.

Several studies listed in Table 4.1. have only indirectly provided insights into the possible effects of caregiver touch on infant oxytocin, through investigating caregiving qualities associated with increased use of affectionate touch. The results were mixed: some have found maternal engagement (talkativeness, proximity, attention observed during an interaction in the lab) to be predictive of increased oxytocin system activity in full-term infants through negative associations with OXTRm (Krol et al., 2019), but it was also reported to be negatively associated with salivary oxytocin in premature infants, when the engagement was assesed with a self-report measure, consisting of subscales such as Self- efficacy, Social Support, Outcome Expectations and Intent, Knowledge and Awareness of Development, and Perception of Risk (Vittner et al., 2019). In a study in which the effects of intranasally administered oxytocin on fathers' caregiving behaviours and infant oxytocin levels were investigated, Weisman et al. (2012) found that oxytocin administration led to higher "social reciprocity" and parental touch in fathers, but also to an increase of oxytocin in full-term 5-month-olds. However, no direct associations between fathers' touch and infant oxytocin were reported. Meanwhile, Fujiwara et al. (2019) found no associations between mother's current bonding and parenting to her infant, as measured with the Mother-Infant Bonding Scale, and salivary oxytocin in full-term 3-10-month-olds. Interestingly, Markova (2018) found that time spent playing social games during a parent-child interaction was negatively associated with infant salivary oxytocin.

It is very hard to generate a clear interpretation of the abovementioned studies, given the variety of caregiving qualities investigated, the differences in methodology and age of participants. Few of the studies discussed have looked particularly into touching behaviours, and those that did, led to contradictory or null results. We do not know enough to confidently conclude that caregiver touch leads to oxytocin release in human infants.

4.1.2.1. Why should caregiver touch lead to oxytocin release in human infants?

With the evidence described above in mind, it is worth asking what the functional purpose and the what mechanisms would be behind an increase in oxytocin in response to caregiver touch in human infants? Of course, the immediate and most obvious answer to this question would draw on the evidence from rodent studies. Yet, several important factors differentiating human babies from rat, mouse or praire vole pups need to be taken into consideration. Firstly, human babies are born relatively helpless and have unusually long childhoods, compared to other animal species (Kaplan et al., 2000) – in contrast, one of the reasons rodents are such popular research participants is precisely because of their rapid development (Workman et al., 2013). Thus, developmental dynamics cannot be easily translated between, for instance, a rat pup and a human baby; taking weaning as an example, the average weaning age is 3 weeks in rats, and 6 months in humans (Quinn, 2005). This discrepancy in the rate of development has a very relevant consequence: humans are reliant on their caregivers' proximity for an extended period of time. While much of the tactile contact happening during this time serves a clear practical purpose (carrying from one place to another, securing infant's position, feeding, etc.), a lot of it, like kissing, stroking or tickling has a communicative function (Hertenstein, 2002). As discussed earlier, tactile contact in rodents has a communicative function too (Tang et al., 2020), but it can be argued that human infants are subject to a much wider repertoir of tactile stimulation from their caregivers than rat pups are; taking coding scheme categories as an example, rodent studies typically include four to five touching behaviours (Caldji et al., 1998; Tang et al., 2020), while in humans, coding schemes often distinguish up to ten different types of touch (Reece et al., 2016)[11]. At the very least, the touching behaviours across the species are very different. Thus, if licking and grooming has an effect on rat

[11] However, what categories are included in a coding scheme primarily reflects the scientific interest of the researchers, and it could be argued that the much less detailed coding schemes used in rodent studies stem from an anthropocentric perspective rather than actual differences in the diversity of behaviours.

pups' OXTR receptors (F. Champagne et al., 2001), it makes sense to ask what would be an analog of licking and grooming in humans; as discussed in detail in Chapter 1, a lot of scientific effort has focussed on stroking and caressing as a possible human equivalent to licking and grooming (Cascio et al., 2018).

Considering the uniqueness of many touching behaviours in humans, it may be that instead of directly applying the rodent model to human babies, it would be more beneficial to explore putative human specific mechanisms of touch in development (Gliga et al., 2019). This notion could be especially relevant in oxytocin research, inasmuch as oxytocin is implicated in complex social behaviours in humans (Walker et al., 2017), and so it seems that both sides of the equation – the touching side, and the oxytocin side – are significantly more nuanced in humans than they are in rodents.

For example, there are reasons to think that caregiver touch could in certain contexts lead to a decrease rather than increase in infant oxytocin. Firstly, when interpreting their unexpected finding of Kangaroo Care leading to a decrease in salivary oxytocin, Kommers et al. (2018) pointed out that salivary oxytocin has been found to increase in response to stress in adults (de Jong et al., 2015), which could have explained the elevated baseline oxytocin levels in infants in their study (as infants could have been stressed by coming to the lab, the testing situation etc.). Using the same stressor as de Jong et al. (2015), the Trier Social Stress Test, Heinrichs et al. (2003) found that in adults, intranasally administering oxytocin before the stressor enhanced the stress buffering effects of social support from a close friend. It may be that, given oxytocin's involvement in social orienting and augmenting the salience of social signals (Shamay-Tsoory & Abu-Akel, 2016), oxytocin's role in infancy would be to affect stress response indirectly, through guiding a baby's attention to caregivers and and strengthening the stress buffering effects of social support, including touch. Subsequently, when an infant receives the calming, warm touch, their drive to seek social buffering would naturally decrease, accompanied by a decrease in oxytocin levels. This hypothesised model is depicted in Figure 4.2.

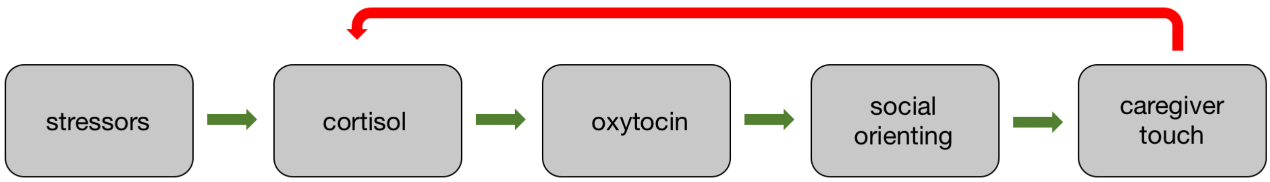

Figure 4.2. Model of a potential mechanism through which caregiver touch could decrease oxytocin levels in infants. Green arrows represent positive, while red – negative effects.

The two-way connection between the paraventricular nucleus, responsible for oxytocin production, and the nucleus of the solitary tract (Morrison, 2016), regulating the hypothalamic-pituitary-adrenocortical axis involved in cortisol response (see Figure 1.2. in Chapter 1), could be the neural architecture behind this putative mechanism. Given how several studies showing links between parental touch and infant oxytocin levels (e.g. Feldman, Gordon, et al., 2010; Weisman et al., 2012) present correlational findings with varying sampling times, it is conceivable that rather than tactile stimulation from the parent elevating oxytocin levels in the baby, it could be that higher oxytocin levels in the baby lead to them seeking attention from their caregivers, for example through increased gaze to faces (Nishizato et al., 2017), soliciting more touch from the caregiver. This mechanism would, of course, have to rely on parental ability to detect and respond to infant cues. In this context, the results obtained by Markova (2019) are very interesting: she found that salivary oxytocin levels in 4-month-olds were positively associated with their gazes at mother, but only in those infants whose mothers exhibited high affect attunement (defined as maintaning attention on the baby, and warm sensitivity). Although the study did not investigate this directly, it seems plausible that the mothers high in affect attunement also engaged in more touching in response to their babies' gazes. In conclusion, rather than being a result of tactile stimulation, increased oxytocin levels in infants may lead to increased tactile stimulation – provided that caregivers are well tuned to their babies.

Later on in development, as reciprocity in relationships becomes more important, interpersonal touch would also, secondarily, lead to oxytocin release (possibly through top-down modulation; see Chapter 1, section 1.3.1. on the connections between the oxytocin release site and neocortical structures), a phenomenon that has been better documented in adults (e.g. Grewen et al., 2005; Morhenn et al., 2012). This would cause a person to want to return a hug from a friend (through strengthening a reinforcement value of the hug), or an adult to pay more attention to what emotion their partner, who is stroking them, is expressing (through enhancing the salience of their facial expression). Interestingly, in situations where reciprocity is not expected, for instance in interactions with robots, human adults show a decrease, rather than increase in oxytocin levels: Geva et al. (2020) showed that touching a soft seal-like PARO robot caused a decrease in pain ratings (pain was administered through a thermal stimulator attached to the participant's forearm), which was accommpanied by a decrease in oxytocin. For a baby who likely has not developed sufficient regulatory mechanisms or physical independence which would allow them to tune in and out of social interactions, touch leading to oxytocin release could be a recipe for overstimulation. If parental touch led to oxytocin release, which, in turn, would lead to the baby seeking their parent's attention, and, consequently, the parent maintaining their engagement in touching interaction – that could potentially result in a hard to break cycle of social stimulation; yet another reason to speculate that touch could lead to decrease in oxytocin in early development.

If caregiver touch leads to oxytocin increase in infants, we should observe a positive association between caregiver touch observed in the lab and oxytocin measured after the parent-infant interaction, or an increase of oxytocin from before the interaction to after the interaction. However, if the hypothesis that higher oxytocin levels in the infant elicit more touch from the caregiver followed by a decrease in oxytocin is true, we would expect oxytocin measured before the interaction to positively predict parental touch, and parental touch during the interaction would be negatively associated with infant oxytocin after the interaction, with more touch being associated with a larger decrease from before to after the interaction.

4.1.3. Caregiver touch and infant oxytocin and cortisol - summary

Animal research suggests that tactile stimulation provided by the caregiver has consequences on the offspring's oxytocin release (F. Champagne et al., 2001). Oxytocin's role in enhancing the salience and reward value of social stimuli has been shown in humans (e.g. Guastella et al., 2008; Nishizato et al., 2017), and so it is conceivable that caregiver touch could shape infant social orienting by modulating the oxytocin system. However, the few studies investigating oxytocin response to caregiver touch in human infants have brought mixed results, with some even pointing to the possibility of touch leading to a decrease in oxytocin (Kommers et al., 2018; Markova, 2018).

Compared to oxytocin research, more is known about how infant cortisol activity is shaped by caregiver touch, with both basal (Vittner et al., 2017) and reactive (Feldman et al., 2014) cortisol being dampened by tactile stimulation, as described in more detail in Chapter 1. When everyday naturally occurring caregiver touch is considered, particularly stroking (Fairhurst et al., 2014) and holding/cuddling (Morrison, 2016) seem to be of relevance in regulating infant arousal.

4.1.4. Present study

The majority of studies on the associations between caregiver touch in infancy and infant hormonal response to date have featured infants born prematurely. Moreover, they have largely focused on interventions in parental behaviours (such as Kangaroo Care) rather than spontaneous parental touching habits. In contrast, animal research suggests that the naturally occurring variation in caregiver touching can have lasting consequences on an offspring's cortisol and oxytocin activity, indicating lasting effects on stress response and social behaviour.

The aim of the present study was to investigate how naturally occurring variation in caregiver touch is associated with salivary oxytocin and cortisol levels in full-term infants aged between 6 and 13 months. Building on the previous study (Chapter 3), in which we extracted dimensions of caregiver touch emerging from various measures, we used the two dimensions – which we labelled as Self-reported and Observed caregiver touch - as predictors of infant hormone levels. Self-reported touch here indicates parental beliefs about and perceptions of their caregiving touch-related behaviours, which are fairly stable over time. The Observed touch dimension represents touch observed in the lab. Higher scores on both dimensions indicate higher quantities of touching interactions. Thus, if Self-reported touch rather than Observed touch was shown to predict infant hormonal levels, we take this to imply long-term effects of caregiver touching habits on infant stress response and oxytocin function.

In contrast, the presence of associations between the hormone levels and the Observed touch dimension could indicate short-term effects of touch on infant cortisol and oxytocin levels. It is however important to also consider the possible bi-directionality of these associations such that infant salivary cortisol and oxytocin could predict parental touching, with higher levels of both hormones eliciting more touching from the caregiver. We aimed to assess these hypotheses by looking at the associations between observed caregiver touch and infant cortisol and oxytocin before and after the interaction (as well as a relative decrease/increase in hormone levels).

4.2. Methods

4.2.1. Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and 18 females) and 11-

to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females) and their primary caregivers.

4.2.2. Measures

4.2.2.1. Caregiver touch

I employed several measures of caregiver touch, both based on self-report (Parent Infant Caregiving Touch Scale, Social Touch Questionnaire, Touch Diary) and observation (derived from filmed parent-child interactions). Using a Principal Component Analysis approach on these measures, described in detail in Chapter 3, I identified two dimensions I believe represent self-reported caregiver touch (or, habitual, long-term patterns in caregiver touch; Dimension 1) and directly observed touch (or, short-term, contextual touching; Dimension 2). In this study, I used caregiver's scores on these two dimensions as indicators of the quantity of self-reported and observed touch an infant received.

4.2.2.2. Salivary oxytocin

I obtained infant saliva samples using Salivettes® (Sarstedt, Rommelsdorf, Germany; see Figure 4.3.). The parents were asked not to feed their children 45 minutes prior to their arrival to the lab. Samples were collected at the beginning of the dyad's visit in the lab, shortly after acquainting them with the lab, and after an approximately 40 minute period of parent-infant interaction (see Chapter 2 for detailed protocols and timings), resulting in a maximum of two samples per infant. At each time, parents were asked to put on a glove and put the Salivette® in their child's mouth for them to chew for 1 minute until it was saturated with saliva (see Nishizato et al., 2017). During saliva collection, the caregivers could position the infant however they wanted, to make the saliva collection procedure as comfortable for the infant as possible. Throughout this procedure, the experimenter blew bubbles to entertain and distract the infant.

Figure 4.3. A Salivette® (Sarstedt, Rommelsdorf, Germany) used to collect infant saliva.

Saliva samples were frozen and stored at −20 °C until assay. A commercially available kit (Oxytocin EIA kit, ADI-901-153, Enzo Life Science) was used to determine the concentration of OT. The limit for detection of the assay was 8.3 pg/mL (this is comparable with previous studies; e.g. Markova, 2019). Saliva was recovered from the swabs by centrifugation. The assay procedure meticulously followed the kit's instructions (and was comparable with e.g. Huffmeijer et al., 2012 and Markova, 2019) and was performed by a trained technician.

Four measures of oxytocin activity were used in this study:

1) OT1 – salivary oxytocin at timepoint 1, at the beginning of the visit; representing infant's baseline oxytocin level
2) OT2 - salivary oxytocin at timepoint 2, after ~40 minutes of parent-child interaction; likely representing infant's oxytocin level in response to interaction with the caregiver

3) OT AUC – area under the curve with respect to increase, an index of increase/decrease in oxytocin level which incorporates information about time distance between the measurements (Pruessner et al., 2003)
4) Mean OT – an average of OT1 and OT2, or just one of the two values if the other one was not available for a given participant; a measure capturing an average oxytocin level during the visit, potentially yielding a trait-like oxytocin index

4.2.2.3. Salivary cortisol

Infant saliva samples were obtained using Salivettes® Cortisol (Sarstedt, Rommelsdorf, Germany), which are designed to achieve precise analytical values from small volumes, making them very useful with infants. To minimise the effects of the diurnal cortisol rhythm (Bright et al., 2012; de Weerth et al., 2003), the visits were scheduled in the morning and early afternoon hours (9AM – 2PM), when basal cortisol does not show associations with the time of sampling in infants (de Weerth & van Geert, 2002). As with the salivary oxytocin, samples were collected at the beginning of the dyad's visit in the lab (right after collecting the oxytocin saliva sample), shortly after acquainting the infant-caregiver pair with the lab, and after an approximately 40 minutes long period of parent-infant interaction (again, after collecting the oxytocin saliva sample; see Chapter 2 for detailed protocol and timings). The saliva collection procedure was identical to the one used for obtaining saliva samples for oxytocin, described above. Saliva samples were frozen and stored at −20 °C until assay. The assay was performed by a trained technician using the commercially available Salimetrics® Cortisol Enzyme Immunoassay Kit, with a <0.007 ug/dL sensitivity (comparable with previous studies, e.g. Blair et al., 2008; Thomas et al., 2017).

Similarly to oxytocin, we used four different measures of cortisol activity in this study:

1) CORT1 - salivary cortisol at timepoint 1, at the beginning of the visit; representing infant's baseline oxytocin level
2) CORT2 - salivary cortisol at timepoint 2, after ~40 minutes of parent-child interaction; likely representing infant's cortisol level in response to interaction with the caregiver
3) CORT AUC – area under the curve with respect to increase, a widely used index of increase/decrease in cortisol level which incorporates information about time distance between the measurements (Pruessner et al., 2003)
4) Mean CORT - an average of CORT1 and CORT2, or just one of the two values if the other one was not available for a given participant; a measure capturing an average cortisol level during the visit, possibly yielding a trait-like cortisol index

4.2.3. Procedure

A detailed description of the study procedure can be found in Chapter 2. All hormonal measures were collected during the dyad's single visit at the lab. The caregiver touch measures were collected during the visit, and, in case of Touch Diary, during the 7 consecutive days after the visit.

4.2.4. Analytical Approach

I first looked at the associations between hormone levels and infant age, to see if I could observe a normative decrease in basal cortisol (as observed by e.g. de Weerth & van Geert, 2002; Gunnar et al., 1996) and possibly also oxytocin (as observed by Nishizato et al., 2017 - but see the discussion of the finding in section 4.1.1.1. of this chapter), which would validate these measures. I also looked into the associations between the measures of cortisol and oxytocin, to investigate the intraindividual stability of the measures. I then went on to perform a series of regressions to investigate whether Self-reported caregiver touch predicts infant basal hormone levels, controlling for infant age, which would suggest long-term effects of caregiver touch on cortisol/oxytocin activity. I also performed regressions to verify if infant cortisol and oxytocin levels after the interaction with the parent, as well as a relative change from before to after the interaction, could be predicted by the quantities of Observed touch, suggesting short-term effects of tactile stimulation received while in the lab. Next, I performed regressions testing the hypothesis that higher infant cortisol and oxytocin before the interaction would predict more observed touch from the caregiver. Finally, I conducted an exploratory investigation into correlations between the two hormone levels and most common types of touch (hug/hold/cradle, static, stroke/caress, moving limbs/body and kiss/pat) employed during parent-child interaction in the lab (see Chapter 3, Table 3.2. for detailed descriptive statistics). Previous literature suggests that hugging/holding/cradling as well as stroking may elicit a decrease in cortisol and increase in oxytocin.

4.3. Results

There was a substantial amount of missing data for OT1 (44%), OT2 (39%), CORT1 (18%) and CORT2 (20%), due to insufficient volume of saliva collected (and, in some cases, possibly an error in computing OT, i.e. concentrations below the limit of detection). This particularly affected the oxytocin measurements, as oxytocin assays require higher volumes of saliva than do cortisol assays. The amount of missing data is comparable with Markova (2019), who reported 30-50% missing values in her study with 4-month-olds. Additionally, four OT2 values and eight CORT2 values were excluded from the analysis due to the mothers feeding their children during the period of interaction between collection of the samples, yielding a final sample of n = 40 for OT1, n = 39 for OT2, n = 58 for CORT1 and n = 49 for CORT2.

4.3.1. Associations with infant age, and between cortisol and oxytocin

Table 4.2. Spearman's rho correlations between CORT1, CORT2, OT1, OT2 and infant age (in days)

		CORT1	CORT2	OT1	OT2
infant age	correlation coefficient	-0.380	-0.397	0.123	0.202
	Sig. (2-tailed)	0.003	0.005	0.448	0.217
	N	58	49	40	39

Table 4.2. shows the correlations between infant age and cortisol at timepoint one (CORT1), cortisol at timepoint two (CORT2), oxytocin at timepoint one (OT1) and oxytocin at timepoint two (OT2). I observed a decrease in cortisol with infant age, which was expected as per the previous literature (de Weerth & van Geert, 2002; Gunnar et al., 1996). No significant correlations between infant age and oxytocin at either timepoint were detected. However, a negative correlation between salivary oxytocin levels and age in early development has only been reported in one study (Nishizato et al., 2017), which included a much broader age range (5 to 90 months). Based on a visual inspection of their data (see Figure 4.1.) it could be argued that the negative association was not well explained by a linear regression model, and was rather caused by the broad variability of oxytocin levels among the youngest participants. Therefore, I believe that the lack of correlation in our study does not invalidate the measure.

Table 4.3. shows correlations between measures of oxytocin and cortisol. Oxytocin was not correlated with cortisol at any timepoint. However, OT1 and OT2 were positively correlated ($r = 0.386$, $p = 0.035$, $n = 30$), and so were CORT1 and CORT2 ($r = 0.273$, $p = 0.067$, $n = 46$), though the latter correlation did not quite reach statistical significance. These findings indicate a degree of intraindividual stability, and thus a likely trait component in the hormonal measures.

Table 4.3. Pearson correlations between OT1, OT2, CORT1 and CORT2

		OT1	OT2	CORT1	CORT2
OT1	correlation coefficient		0.386	-0.097	-0.134
	Sig. (2-tailed)		0.035	0.556	0.471
	N		30	39	31
OT2	correlation coefficient			0.020	0.049
	Sig. (2-tailed)			0.907	0.781
	N			38	35
CORT1	correlation coefficient				0.273
	Sig. (2-tailed)				0.067
	N				46

4.3.2. Predicting infant cortisol and oxytocin with Self-reported touch

In order to assess whether I could predict basal levels of cortisol and oxytocin with self-reported quantities of caregiver touch occurring in infant everyday life, which would indicate long-term effects of touch on infant hormonal activity, I performed two linear regression models: one predicting infant mean cortisol levels from parental Self-reported touch, controlling for infant age and parental Observed touch, and another predicting infant mean oxytocin with the same predictors.

The model predicting mean cortisol levels with caregiver Self-reported and observed touch as well as infant age was significant ($F(3, 56) = 9.065$, $p < 0.001$, $R^2 = 0.327$, explaining 32.7% of the observed variance. However, parental Self-reported touch was not a significant predictor of infant mean cortisol level ($\beta = -0.031$, $t(56) = -0.285$, $p = 0.777$). Only parental Observed touch ($\beta = 0.294$, $t(56) = 2.397$, $p = 0.020$) and infant age ($\beta = -0.377$, $t(56) = -3.066$, $p = 0.003$) significantly predicted infant mean cortisol, with more Observed touch being associated with higher cortisol, and older infants exhibiting lower cortisol.

These findings do not support the hypothesis that higher amounts of caregiver touch occurring in everyday life would be associated with lower basal cortisol in infants. Rather, I found that only observed caregiver touch was associated with infant cortisol during the visit at the lab.

The model predicting mean oxytocin levels with caregiver Self-reported and Observed touch, as well as infant age was not significant ($F(3, 44) = 0.378$, $p = 0.769$, $R^2 = 0.025$). I did not find evidence supporting the hypothesis that higher levels of Self-reported caregiver touch are associated with higher levels of infant oxytocin.

4.3.3. Predicting parental touch from infant OT1 and CORT1

In order to test whether parental touch observed in our study was induced by infant distress levels pre-interaction (as indicated by cortisol), I performed two linear regression models predicting parental Observed touch during the session from infant cortisol (the first model) and oxytocin (the second model) at timepoint 1, controlling for infant age. Due to the differing numbers of available data points for CORT1 and OT1 I did not enter both these variables into one model.

The model predicting Observed caregiver touch with infant pre-interaction cortisol levels and age was statistically significant ($F(2, 55) = 11.261$, $p < 0.001$, $R^2 = 0.291$), and explained 29.1% of observed variance. Infant cortisol before the interaction predicted the quantity of Observed parental touch ($\beta = 0.333$, $t(55) = 2.650$, $p = 0.010$), when controlling for infant age ($\beta = -0.305$, $t(55) = -2.424$, $p = 0.019$), with higher levels of infant cortisol being associated with more touch from the caregiver (see Figure 4.4.).

The model predicting Observed caregiver touch with infant pre-interaction oxytocin levels and age was also significant ($F(2, 37) = 3.391$, $p = 0.044$, $R^2 = 0.155$), explaining 15.5% of observed variance. However, only infant age was a significant predictor in this model ($\beta = -0.388$, $t(37) = -2.554$, $p = 0.015$), with OT1 not being associated with the quantities of caregiver touch Observed during the interaction (β = 0.119, t(37) = 0.785, p = 0.437). Our data therefore does not provide support to the hypothesis that higher oxytocin levels in the infant would elicit more touch from the caregiver.

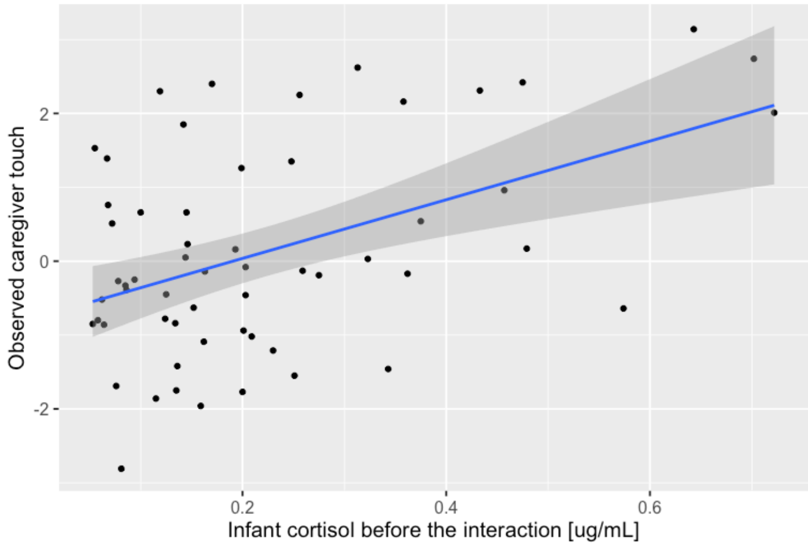

Figure 4.4. Association between infant cortisol levels before the interaction and Observed caregiver touch dimension

4.3.4. Predicting a change in infant cortisol and oxytocin with observed caregiver touch

I performed two linear regression models testing whether a decrease/increase in cortisol and oxytocin from pre- to post-interaction could be predicted with parental touch Observed in the lab, controlling for Self-reported touch, indicating short-term effects of caregiver touch on infant hormonal reactivity.

The model predicting CORT AUC with parental Observed touch, Self-reported touch and infant age was not significant ($F(3, 40) = 0.494$, $p = 0.688$, $R^2 = 0.036$), nor was the model predicting OT AUC with the same predictors ($F(3, 25) = 0.389$, $p = 0.762$, $R^2 = 0.045$). These results do not support the hypothesis that a change in infant cortisol and oxytocin levels is associated with parental short-term or long-term touching patterns.

4.4.4. Types of touch and oxytocin and cortisol levels

Although I did not find associations between the general quantity of Observed touch and infant CORT AUC and OT AUC (see previous section), I was interested in whether the change in hormone levels could be associated with specific types of touch. I conducted an exploratory investigation into the associations between the most commonly employed types of touch during parent-child interaction in the lab and infant CORT AUC and OT AUC. The five most commonly employed types of touch were: hug/hold/cradle, stroke/caress, moving limbs/body, kiss/pat and static touch. The total durations of these touch categories during PCI-FP and PCI-Q were added up to create one composite measure per type of touch. I hypothesised that, given the significance of these types of tactile stimulation as indicated by previous literature, hug/hold/cradle and caress/stroke could exhibit significant positive associations with the measure of change in oxytocin levels, and negative associations with the measure of change in cortisol levels.

The correlations between the touch types and CORT AUC as well as OT AUC are shown in Table 4.4. (the significance levels are not corrected for multiple comparisons). I have not found evidence for associations between any of the five touch types and change in infant cortisol or oxytocin.

Table 4.4. Spearman's correlations between the durations of most commonly used types of touch during parent-child interaction and infant CORT AUC and OT AUC

		hug/hold/cradle	stroke/caress	moving limbs/body	kiss/pat	static
CORT AUC	correlation coefficient	0.039	-0.072	0.188	0.254	0.038
	Sig. (2-tailed)	0.812	0.66	0.244	0.114	0.818
	N	40	40	40	40	40
OT AUC	correlation coefficient	0.311	-0.103	0.101	-0.218	-0.067
	Sig. (2-tailed)	0.122	0.617	0.624	0.286	0.744
	N	26	26	26	26	26

4.5. Discussion

I did not observe associations between naturally occurring variation in caregiver touch and infant cortisol and oxytocin levels in the expected directions. Neither self-reported touch, indicative of habitual long-term patterns of touching behaviours present in infant everyday life, nor touch observed during a parent-infant interaction in the lab were predictive of infant basal and reactive cortisol and oxytocin.

However, I found that caregiver touch observed during the interaction was predicted by infant cortisol levels before the interaction. The higher the cortisol (indicating more stress experienced by the infant), the more touch the parent exhibited during the interaction. Age is an important factor in infant baseline cortisol levels (see de Weerth & van Geert, 2002), and may also be a factor in how parents use touch with their infants, particularly important factor in the context of infant motor development. Indeed, increased motor independence, infants rely less on parental proximity and so touch interactions are necessarily different. However, even when controlling for infant age, cortisol levels before the interaction still predicted observed caregiver touch. This is consistent with the idea that parents were employing more touch in attempts to relax or calm their baby down. Yet, no associations were detected with regards to infant oxytocin pre-interaction and observed caregiver touch, contrary to our hypothesis that higher oxytocin levels would elicit more touch from the caregiver. It seems that infant stress levels, as indicated by cortisol, are a tangible signal for the parent to adjust their behaviour, whereas higher oxytocin levels, which could indicate the infant's enhanced interest in social stimuli and interaction, might require a certain level of caregiver sensitivity for them to respond with touch (as suggested by the results of Markova, 2019). A revised model of the mechanisms behind touch – hormones associations with infant display of distress included as an important factor is shown in Figure 4.5.

With higher pre-interaction cortisol levels eliciting more touch from the caregiver, it is curious that more touch from the caregiver did not translate into an eventual in cortisol. It may be that infant's response to caregiver touch depends on the properties of touch provided by the parent. For instance, it has been shown that a decrease in infant heart rate in response to stroking is dependent on the speed of stroking (Aguirre et al., 2019; Fairhurst et al., 2014). It has also been shown that parents spontaneously employ optimal stroking speeds when interacting with their babies (Bytomski et al., 2020). Perhaps some parents are better than others at employing the types of tactile stimulation which have the most pronounced calming effects on the infant, which, again, could be mediated by parental sensitivity. Thus, we might expect that it would not be the measure of a total quantity of observed touch which would predict a change in cortisol (or oxytocin), but rather only particular types of touch.

However, in this study I found no associations between the five most commonly employed types of touch (hug/hold/cradle, stroke/caress, kiss/pat, moving limbs/body and static) and the change in cortisol or oxytocin levels. I had suspected that stroking and holding could be particularly relevant in regulating infant's arousal, however I did not find evidence for this hypothesis.

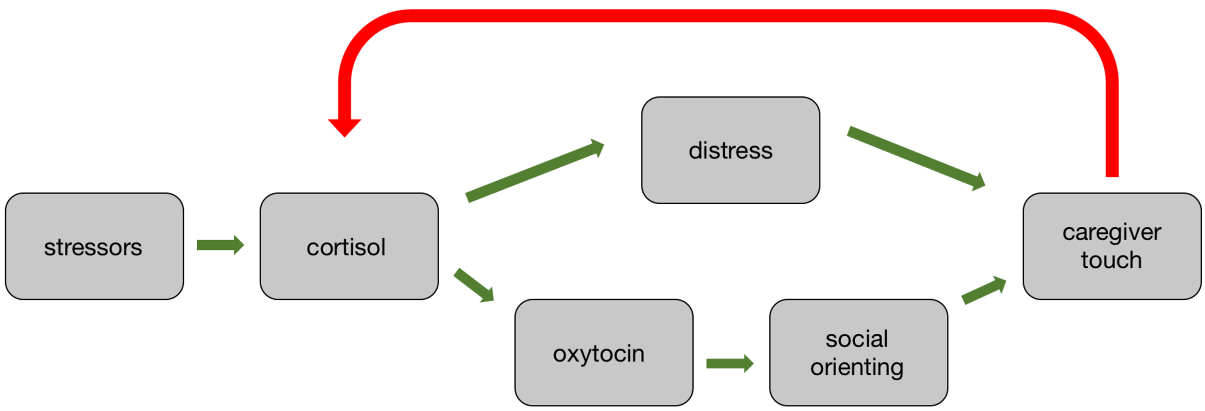

Figure 4.5. Revised model of the mechanisms behind caregiver touch – hormones associations

With regard to long-term correlates of caregiver touch, the lack of associations between self-reported quantities of caregiver touch and infant basal and reactive cortisol and oxytocin could, in fact, mean that no such associations exist. Or, perhaps, other measures of endogenous hormonal activity, for example OXTRm (Krol, Moulder, et al., 2019) could be more suited to capture long-term consequences of prolonged patterns of touch.

Finally, the present study has several limitations. A particularly significant one is the amount of missing data for the hormone measures, especially oxytocin. Although comparable with other studies (e.g. Markova, 2019), the amount of missing data resulted in a sample size which could have been inadequate for studying the putative associations. Moreover, even though I have taken the timing of the measurements into consideration, the correlational design of our study does not allow for making strong causal inferences with regard to the associations found.

To conclude, I have not found evidence for the impact of naturally occurring variation in caregiver touch on infant hormonal activity. The sheer quantity of touch received by the baby, whether reported by parents or observed in the lab, was not associated with either basal or reactive oxytocin and cortisol measures. It is plausible that infant hormonal response to touch is modulated by context cues, as well as caregiver qualities such as parental sensitivity, which our study did not assess. Future directions in the field of caregiver touch research should include more well-controlled experimental designs where different types of touch are administered across a variety of contexts.

In the next chapter, before exploring the associations between caregiver touch, infant hormones and exploratory behaviour, I present an investigation into the associations between various measures of infant exploratory behaviour.

Chapter 5

Comparing measures of infant information sampling strategies

5.1. Introduction

The animal studies demonstrating the influence of caregiver tactile stimulation on offspring's exploratory behaviour have focused on behaviours such as novel object approach and manipulation, or locomotion in novel environment (e.g. Caldji et al., 1998; Guardini et al., 2016; Simpson, Sclafani, et al., 2019). Similar measures have been employed in developmental research with human infants, although not typically in the context of investigating the effects of caregiver touch (e.g. Bornstein et al., 2013; Putnam & Stifter, 2005; van den Boom, 1994). Additionally, with the expanding capability of eye-tracking technology, an increasing number of studies have also investigated visual exploration in human infants (e.g. Gliga et al., 2018; Koch et al., 2018; Wass et al., 2015).

In order to advance our understanding of how caregiver touch affects exploration, our understanding of the mechanisms underlying information sampling strategies in human infants needs to be improved as well. Is classically defined exploratory behaviour, in the form of engaging with novel objects and probing novel environments, driven by the same information sampling strategies as visual exploration of scenes and objects?

In this chapter, I introduce two putative mechanisms underlying exploratory behaviour which may be affected by caregiver touch (as suggested by previous literature): *sustained attention* and *novelty approach*. The feasibility of capturing these dimensions in toy exploration and visual attention-based tasks is discussed. I also present a study investigating the associations between measures supposedly tapping into sustained attention and novelty approach, derived from toy-exploration and eye-tracking tasks.

5.1.1. What is exploratory behaviour?

From zebrafish (Baker et al., 2018) to dogs (Guardini et al., 2016) and through to humans (e.g. Bornstein et al., 2013; Muentener et al., 2018), researchers have identified behaviours they have labelled as "exploratory". One early definition of exploratory behaviour posits that exploratory behaviours are "those behaviours in which an animal appears to take a certain initiative in finding out more about its environment" (McReynolds, 1962, p. 311). A more recent definition, focused specifically on human children, says that exploratory behaviour is a "focused investigation as a child gets more familiar with a new toy or environment" (Smith & Pellegrini, 2013, p. 1). A common denominator to both these definitions is an emphasis on an agent's intention to learn about the environment. Thus, in this view exploration is an active rather than a passive act of obtaining information. Active learning, by definition, requires the agent's behaviour to vary with the novelty of the object, which is also what some consider the most important criterion for exploratory behaviour (Ruff, 1989).

On the surface, it could be surprising that looking is considered an example of exploratory behaviour - however, it satisfies the key criterion of varying with the novelty of the stimulus (Ruff, 1989). Generally, if stimuli are sufficiently complex, infants initially look longer at familiar stimuli, before shifting to novel stimuli (Hunter et al., 1983; Roder et al., 2000; Sirois & Mareschal, 2002). Such behaviour allows the infant to optimise their learning progress, through sustaining the attention on an object for as long as uncertainty is decreasing (i.e. as long as learning is happening; Oudeyer et al., 2016).

Infants can gain complex knowledge about the world simply by means of looking (Aslin, 2007; Johnson, 2010). For instance, learning to perceive object unity (i.e., to perceive a partially occluded object as a single object) can be achieved through looking, without engaging in other means of exploration, provided that the infant is exposed to appropriate visual input (Mareschal & Johnson, 2002).

However, as infants grow and develop their fine and gross motor skills, new ways of actively engaging with the environment arise (although, interestingly, even newborns are capable of types of oral and manual object examination; e.g. see Rochat, 1987). Infants combine multiple means of exploration to gain different modality information about an object, for instance, 5-month-olds are likely to mouth a novel object, and then look at it immediately afterwards (Ruff et al., 1992). Later on, infants rotate, squeeze, throw and manipulate novel toys more often, in attempts to find out as much as possible about their features (Lobo et al., 2015). These actions vary with the novelty of the objects, object properties, and contexts in which exploration occurs in ways that confirm information-seeking goals of these actions (Gliga, 2018; Molina & Jouen, 2004; Rochat, 1983; Steele & Pederson, 2016).

The way infants manually explore novel toys has been found to be associated with several abilities, including their object segregation (Needham, 2000), mental rotation (Schwarzer et al., 2013) and visual prediction skills (Kubicek et al., 2017). Through reaching for, grasping and fingering objects infants learn not just about the objects and the world surrounding them, but also about their own motor abilities (Gliga, 2018).

Early manual exploratory behaviours predict later general cognitive competency. For instance, longer overall duration of engagement with a novel toy at 8 months predicted the score on Bayley Mental Scale at 2 years (Kopp & Vaughn, 1982). Muentener et al. (2018) found that the number of different pre-specified functions of a toy that a 12-month-old discovered within a limited time was correlated with their IQ scores at 3 years. Infant exploration at 15 months, indicated by self-generated variability in object images, predicted their vocabulary growth over the following 6 months (Slone et al., 2019). The extent and efficiency of exploration in infant's home environment at 5 months was predictive of academic achievement as late as at 14 years (Bornstein et al., 2013). Bornstein et al. (2013) concluded that early exploratory competence triggers a developmental cascade, shaping the intellectual functioning of a child.

Is it then reasonable to hypothesise that visual exploration is driven by the same information sampling strategies that drive manual object exploration? At around 6 months, infants' looking behaviour becomes primarily under endogenous control (Courage et al., 2006). As discussed above, both visual and manual exploration seem to follow patterns consistent with the learning progress hypothesis (Oudeyer et al., 2016). Exploration often happens in multiple modalities at the same time, providing different types of information sampled in parallel. There is evidence that when presented with visual stimuli on a screen, infants attend differently to objects depending on their "graspability", encoding different features depending on whether or not an object presented on the screen would normally elicit a manual action (Kaufman et al., 2003). On the other hand, through manually manipulating an object, the infant can generate a diverse visual input (Slone et al., 2019). Visual exploration is therefore tightly connected to manual exploration, in the sense that not only do these two modalities provide complimentary information about objects, but they actually interact.

To be effective, exploration in any modality requires not just shifting attention between familiar and novel objects, but also sustaining attention on an object long enough to enable learning (Oudeyer et al., 2016). When learning ends (in other words, how long attention on an object is sustained) is subject to individual differences, and is likely modulated by novelty drive; if higher value is assigned to new vs. old information, attention should be sustained until the novelty wears off (i.e. a novel object becomes a familiar one). The speed with which the familiarization happens would, in turn, depend on the efficiency of encoding new information, therefore resulting in a non-linear relation between novelty drive and sustained attention, moderated by how fast new information is encoded (Hunter et al., 1983; Sirois & Mareschal, 2004).

Furthermore, both the ability to sustain attention and novelty drive could be affected by environmental factors and changes in internal states of the infant – which is a key assumption behind the investigations into the role of touch in promoting exploratory behaviour in infancy. However, before addressing this overarching question, I will turn to the question of the mechanisms driving exploratory behaviour in infancy. As broadly-defined exploration in infancy has been assessed in a variety of paradigms, the objective of this chapter is to describe how these putative mechanisms have been operationalised, and if the existing measures manifest themselves in consistent ways across various tasks.

It is reasonable to expect that the underlying "building blocks" driving infant exploratory behaviour, novelty drive and sustained attention, would manifest themselves both in interactions with toys and other real-life objects, as well as with visual stimuli. In fact, such an assumption underlies many studies with infants. In the following sections I provide an overview of studies – using both manual exploration and infant looking preferences - aiming to characterise the major drivers of exploratory behaviour: sustained attention and novelty preferences.

5.1.2. Sustained attention

Early research on the topic of sustained attention defined it in terms of durations of infant engagement with a stimulus as indicated by their manual activity and facial expressions (Ruff & Lawson, 1990). More recent definitions of sustained attention have shifted the focus onto infant's looking behaviour. For instance, the *longest unbroken look* to a single complex stimulus has been used as an index of infant's ability to sustain attention (e.g. Goodwin et al., 2016; Wass et al., 2011). For the measure to be indicative of sustained attention, these authors assumed that the stimulus needs to be interesting, as attending to a simple, boring stimulus would rather indicate a general motivation to orient toward the screen (Wass et al., 2011). A closely related measure is *peak look* duration to an object presented among other objects; i.e. the longest unbroken look at a single object when there are other objects competing for their attention (e.g. Gui et al., 2020; Hendry et al., 2016). The presence of multiple objects simultaneously in an infant's view may better reflect everyday exploration opportunities and allow the experimenter to capture trajectories of infant attention. In contrast, other researchers have operationalised sustained attention as a *proportion of time* the infant attended to an object or scene within a predefined time window (Brandes-Aitken et al., 2019; Kopp & Vaughn, 1982). All of these measures probably tap into different ways that sustained attention manifests itself, depending on the context. If the focus of an investigation is to capture individual differences in attention during bouts of naturalistic exploration, measuring attention in situations when it has to be distributed might be the best approach.

Sustained attention emerges during the first year of life, and it continues to develop across childhood (Brandes-Aitken et al., 2019; Reynolds & Romano, 2016). Sustained attention in infancy has been shown to correlate positively with executive functions and emotion regulation in early childhood (Brandes-Aitken et al., 2019; Frick et al., 2018), and its impairment is implicated in developmental disorders, such as attention deficit hyperactivity disorder (Barkley, 1997; Goodwin et al., 2016).

Interestingly, the relation between infant sustained attention as measured with looking time paradigms and as assessed during exploration with objects is not an intuitive one. Wass et al. (2011) trained 11-month-olds on a battery of attentional control tasks, which involved stopping the replay of an animation if infants looked away from it, and found that the training led to increases in durations of the longest unbroken looks to interesting, but not boring, stimuli in an eye tracking task – indicating that the effect pertained to sustained attention and not a general tendency to orient to the screen. However, it also led to shorter average durations of looks to novel objects in a free play task, and an increased number of attentional shifts both between objects, and from object to a person (the experimenter or caregiver). The authors proposed that in the eye tracking task, focusing longer on the complex stimulus presented on the screen (rather than looking around the room from which distractors had been removed) was a desirable behaviour, while in a free play task with multiple objects competing for infant's attention, shorter looks and more attention switches were the optimal exploration strategy.

Wass (2014) followed up with a study investigating the associations between peak look durations in screen-based and semi-naturalistic tasks (objects presented on a stage) in 11-month-olds. The tasks varied in the type and the number of presented objects, but in all of them, there was a single area of interest (the screen, or the stage where the objects were presented). Wass (2014) found that while the peak look measures derived from the screen-based tasks showed a high degree of intraindividual agreement, the peak looks in the semi-naturalistic tasks were either not correlated, or negatively correlated with the screen-based measures.

I would speculate that the difference between the screen-based and semi-naturalistic measures in the studies by Wass et al. (2011) and Wass (2014) stems from the fact that in the visual task, the infants were presented with a single object (even if there were more objects present, there was one area of interest), while the object exploration task and the semi-naturalistic tasks effectively had multiple objects (or, areas of interest) in the infant's visual field. Thus, the duration of looking when presented with a single stimulus would indicate the efficiency of information-processing, rather than reflecting infants' ability to sustain attention, while look durations when presented with multiple objects would indeed be driven by infant's internal control of attention (Colombo & Mitchell, 2009; Hendry et al., 2019; Kannass & Oakes, 2008; Tamis-Lemonda & Bornstein, 1993). For instance, consistent with this interpretation, peak look duration during habituation to a neutral female face at 5 months was negatively associated with the levels of symbolic play achieved at 13 months (Tamis-Lemonda & Bornstein, 1993). Kannass & Oakes (2008) found that in 9-month-olds, shorter durations of looks in a single-object task predicted larger vocabularies at 31 months, while the relationship was inverse for look durations in a multiple-object task. By demonstrating the negative correlations between peak looks in single-object tasks and developmental outcomes, these findings further corroborate the notion that peak looks in single-object tasks may capture the efficiency of information processing rather than the ability to sustain attention at the service of learning.

Tamis-Lemonda & Bornstein (1993) posited that attention during visual fixation paradigms functionally differs from attention during exploration with objects, saying that *"shorter visual fixation in laboratory procedures might index more efficient or faster processing in young infants; in contrast, in situations that permit older infants to explore more actively (as during free play), sustained interest (…) appears to index greater competence"* (Tamis-Lemonda & Bornstein, 1993, p. 434). Recently, more researchers have turned to measuring infant attention in more naturalistic settings, using head-mounted eye trackers (e.g. Brandes-Aitken et al., 2019; Yu et al., 2019), which could yield estimates of sustained attention which are more true-to-life, in terms of infant everyday behaviour in their usual surroundings. However, before concluding that there are no "equivalents" between attentional measures as captured in looking time lab-based tasks and infants' exploration of real-life three dimensional scenes, it makes sense to test whether measures collected under comparable conditions (e.g. when multiple objects are presented at once) prove to be more correlated.

Would longer peak looks to an object in a multiple object array predict longer unbroken manual exploration of a toy, when presented among other toys, indicating a common attentional driver to these behaviours? Would shorter looks to novel objects during habituation predict shorter manual exploration when the infant is presented with a single toy, indicating a common factor of efficiency of processing information, both visual and haptic?

5.1.3. Novelty approach

A key driver of exploratory behaviour is novelty preference (Ruff, 1989). A positive response to novelty (approach) facilitates learning of new information, while a negative response (withdrawal) can prevent it. However, approaching unfamiliar objects or individuals can be risky, and animal researchers emphasise the benefits of behavioural flexibility in response to novelty (Forss et al., 2019; Reader, 2015). The way animals respond to novel objects and environments has been shown to be affected by caregiving factors, in ways which suggest that a greater availability of a caregiver, as indicated for instance by more tactile stimulation, promotes assigning a positive rather than negative value to novelty (Guardini et al., 2016; Meaney, 2001; Timmermans et al., 1994).

Like other animals, human infants exhibit individual differences in how fast they approach novel objects (Putnam & Stifter, 2005). Although looking time preferences have most commonly been used as an indicator of infant memory or processing efficiency in visual attention research (Colombo & Mitchell, 2009; Thompson et al., 1991), visual novelty preference is also driven by motivational factors (de Barbaro et al., 2016; Hendry et al., 2019). For instance, newborns and 1-month-old infants show a shift from familiarity preference in a visual attention paradigm before being fed, to novelty preference after being fed (R. Geva et al., 1999). The authors of the study explained this in relation to the infants' arousal levels pre and post feeding (although it is also plausible that feeding could have improved infant visual recognition memory, or general processing efficiency). Furthermore, de Barbaro et al. (2016) found that stress reactivity as measured with beats-per-minute change in heart rate during a stressor video as compared to baseline heart rate positively predicted looking to a novel (vs. familiar) stimulus in 12-month-olds, further suggesting that novelty preference is driven by factors other than just cognition.

It remains unclear the extent to which novelty preference, as observed in looking time paradigms, has the same underlying causes as novelty induced behaviours commonly recorded in animal studies, such as the physical approach of novel objects or locomotion in a novel environment (e.g. Champagne & Meaney, 2007; Simpson, Sclafani, et al., 2019). Preference of novelty exhibited in looking behaviours seems to lack an element of risk inherent to physical exploration of novelty: getting closer to, touching and especially putting an unfamiliar object in one's mouth is potentially far more dangerous than simply looking at it. Nevertheless, a larger preference for novelty over familiarity in the visual modality is likely to capture motivational factors as well, even if it does not fully tap into what animal research typically defines as neophilia (drive to approach and explore novelty – in spite of the risk associated with it; Forss et al., 2019).

An indirect link between novelty preference measured in an eye-tracking task, and a general predisposition to novelty-seeking behaviour in infants was observed by Gliga et al., (2018). The authors tested infants at familial risk of autism spectrum disorders and low-risk controls, and related their visual foraging behaviour to levels of hyperactivity/inattention, associated with increased novelty seeking, in their siblings. Novelty biases were assessed with the likelihood of revisiting a previously looked at object in a visual scene. In 8-month-olds, novelty bias in the eye-tracking task was positively correlated with hyperactivity and inattention score (measured with the Strengths and Difficulties Questionnaire) in the sibling.

Crucially, the measure of novelty preference in this study was not a simple looking time to a novel vs. familiar object. Because there were multiple objects (areas of interest) present within one visual scene, the infant's visual foraging behaviours in this task were a better reflection of the exploratory behaviours occurring in infants' everyday complex surroundings. Because the infants' familiarisation was dynamical and self-driven (by selecting what to view on the slide) rather than as a result of pre-determined habituation task order , this task could capture motivational factors (rather than just processing speed) better than previously used measures of novelty preference.

In summary, I argue that in addition to infants' ability to shift and sustain attention on objects in ways that reflect learning progress, exploratory behaviour is also driven by novelty approach. Moreover, this component should manifest itself not just in naturalistic object exploration (e.g. Putnam & Stifter, 2005), but also in visual exploration (e.g. Gliga et al., 2018). For instance, I would expect that infants who approach (touch) novel toys faster, would look at more objects when presented with multiple objects on a screen.

5.1.4. The present study

Exploratory behaviour in infancy predicts long-term cognitive development (Bornstein et al., 2013; Muentener et al., 2018). Yet, it is not universally agreed how exploratory behaviour in infants should be measured, and various different measures have been employed by different researchers (e.g. Kubicek et al., 2017; Lobo et al., 2015; Muentener et al., 2018). In developmental psychology, "exploratory behaviour" usually refers to infant or toddler behaviour measured when presented with novel toys. This behaviour is generally thought to reflect underlying cognitive or motivational processes (e.g. attention, novelty drive, efficiency of information processing) which should be observable in other paradigms as well (Muentener et al., 2018).

The effects of touch on exploratory behaviour in animals have been demonstrated with object and environment exploration tasks (e.g. Meaney, 2001; Simpson, Sclafani, et al., 2019), but I hypothesise that they should be observable in visual exploration patterns as well. However, the question of whether visual and manual exploration are driven by the same information sampling strategies needs to be addressed first. As discussed above, there have been some discrepancies between measures derived from visual attention paradigms and naturalistic object exploration (e.g. Kannass & Oakes, 2008; Wass et al., 2011; Wass, 2014), and some have posited that these two types of exploration differ functionally (Tamis-Lemonda & Bornstein, 1993). Yet, the differences might be methodological, as naturalistic object exploration involves distribution of attention between potentially many objects of interest, and visual attention screen-based paradigms, the way they have been used most commonly, have not delved into this aspect of exploration. To my knowledge, no study to date has compared visual attention measures towards multiple visual stimuli presented on a screen (and treated as separate areas of interest) and exploratory behaviours observed during toy play.

The aim of the present study was to examine to what extent measures derived from table top manipulation tasks and eye-tracking tasks capture two major aspects of exploration: *sustained* *attention* and *novelty approach*. The toy exploration-based and eye-tracking-based tasks I employed are shown in Figure 5.1. I hypothesised that with multiple objects presented on screen (and areas of interest corresponding to these objects), peak look durations to an object would be positively correlated with peak manual exploration of a toy when multiple toys are presented (Simultaneous exploration toy task), but peak looks to a single complex scene (Sustained attention task) would be negatively correlated, reflecting a functionally different aspect of sustained attention, where the distribution of attention is not accounted for. Furthermore, I hypothesised that I could measure infant novelty approach, by measuring: (1) the number of objects the infant manually explored when presented with multiple toys (Simultaneous exploration toy task), (2) the mean latency to touch a novel toy when presented with one toy at a time (Sequential exploration toy task), and (3) the number of objects looked at when presented with multiple objects on screen (Non-social Pop Out task).

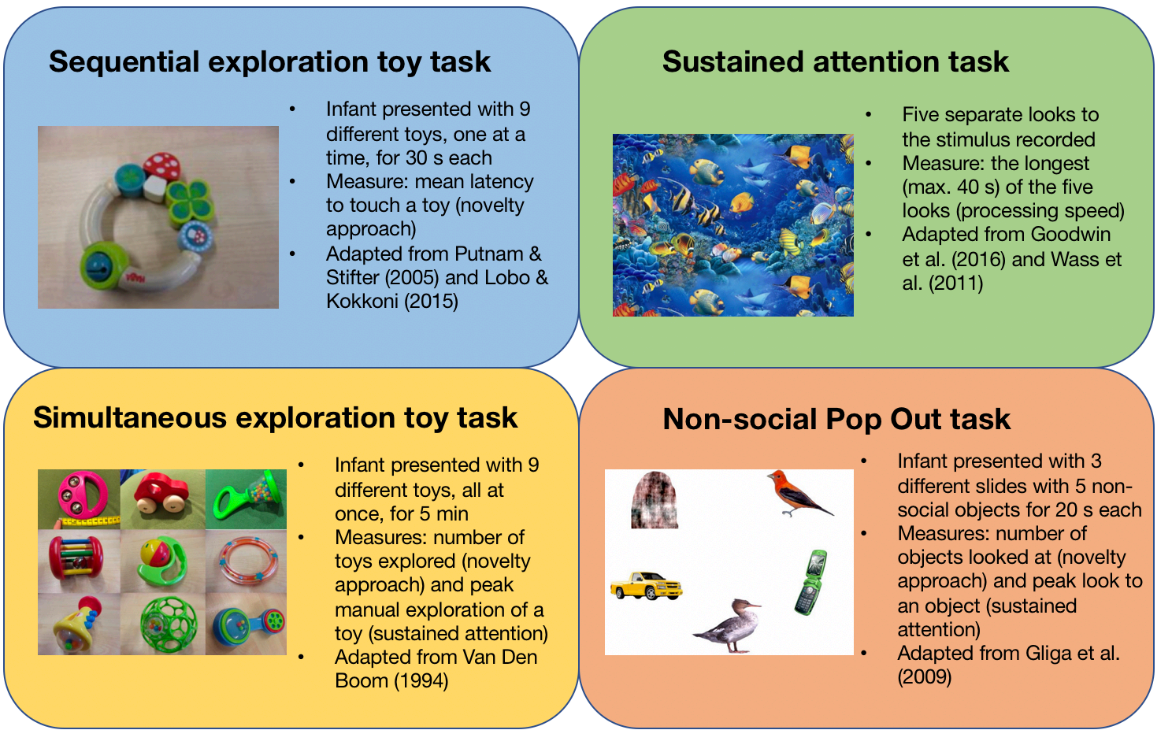

Figure 5.1. Overview of the table top toy-based exploration tasks (left) and eye-tracking visual exploration tasks (right)

5.2. Methods

5.2.1. Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and 18 females) and 11- to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females) and their primary caregivers.

5.2.2. Measures

5.2.2.1. Sustained attention

Three measures of sustained attention were employed in this study: peak manual exploration of a toy in the Simultaneous exploration toy task, peak look duration to an object in the Non-social pop out task, and peak look duration in the Sustained attention task.

5.2.2.1.1. Peak manual toy exploration

Peak manual toy exploration was coded from the video of the infant performing the Simultaneous exploration toy task, in which the infant was presented with 9 different toys at the same time for 5 minutes, or until they were no longer interested. The longest continuous period of manual engagement with a toy constituted peak manual toy exploration. Manual engagement was coded as any type of tactile contact (holding, fingering, rotating, etc.) the infant made with a toy, where the infant's attention was on the toy. If the infant was not looking at the toy while making tactile contact with it, the behaviour was still coded as manual engagement if the infant was actively doing something with the toy (e.g. shaking/rotating it), but not if they were only passively holding it. Peak manual toy exploration measures were only included in the analyses if the infant completed at least 2 minutes of the task.

5.2.2.1.2. Peak look in an array task

Peak looks in an array task were calculated from infant gaze data collected in the Non-social Pop Out Task, in which the infants were presented with three different slides depicting arrays of five different non-social objects (see Figure 5.1.) The slides were presented for 20 seconds each.

The targets were defined as rectangular areas of interest (AOIs) around each stimulus. Contiguous sequences to a single AOI for a minimum of 100 ms were identified as a look. The peak look was identified within each slide from a minimum of two looks. An average of up to three peak looks (one per each slide presented) was calculated for each participant to provide a more stable characterization of individual differences (see Hendry et al., 2018).

5.2.2.1.3. Peak look in the single object task

The longest continuous look to an "interesting", complex stimulus constituted the peak look measure in the Sustained Attention task. Even though the slide consisted of multiple objects (see Figure 5.1.), it was treated as a single, complex stimulus as no areas of interest were defined. This is consistent with how this task has been administered and analysed in previous research (Goodwin et al., 2016; Wass et al., 2011). For each stimulus, the experimenter records the length of the infant's first 5 looks towards the stimulus presentation area (as per Goodwin et al., 2016; Wass et al., 2011). To qualify as a look the infant must visually engage with the stimulus for at least 1 s. To terminate the look, the infant must disengage from the stimulus for at least 1 s. The longest of the 5 looks to the complex stimulus is termed the peak look duration (see Goodwin et al., 2016). This measure was only calculated if a total of 5 separate looks per infant were recorded.

5.2.2.2. Novelty preference

Three measures of novelty preference were employed in this study: latency to touch a toy in the Sequential exploration toy task, number of toys explored in the Simultaneous exploration toy task and number of objects looked at in the Non-social pop out task.

5.2.2.2.1. Latency to touch a toy

In the Sequential exploration toy task, the infant was presented with nine different toys, one at a time, for 30 seconds each. The latency to touch a toy was defined as the time passing between the moment the toy was put on the table (in front of the infant sitting in a high chair) and the infant touching the toy (see Putnam & Stifter, 2005).

5.2.2.2.2. Number of toys explored

In the Simultaneous exploration toy task, the infant was presented with nine different toys on a tray, all at once. The number of explored toys was defined as the number of toys the infant manually engaged with for at least 2 seconds (to avoid coding accidental touches). The criteria for manual engagement with a toy were the same as those defined for peak manual exploration (section 5.2.2.1.1.). This measure was only included in the analyses if the infant completed at least 2 minutes of the task.

5.2.2.2.3. Number of objects looked at

The number of objects looked at was calculated from infant gaze data collected in the Non-social Pop Out Task, in which the infants were presented with three different slides depicting arrays of five different non-social objects, for 20 seconds each. If the infant's eye gaze hit the rectangular AOI of an object for a minimum of 100 ms (like in the peak look measure), the object was considered "looked at", and per each slide, the total number of objects looked at, ranging between 0 and 5, was computed. The infant had to look at the slide for at least 4 seconds (out of the total 20 seconds of presentation) for the measure to be calculated. An average of the number of objects looked at from up to three slide presentations was calculated per participant.

5.2.3. Procedure

All measures were collected during the dyad's single visit to the lab. Following a period lasting about 40-minutes, during which parent-infant interactions were coded and the saliva samples were collected, the infant was presented with table top toy exploration tasks, while being filmed. The first task was the Sequential exploration toy task, followed by the Simultaneous exploration toy task. After the table top tasks, the infant and their caregiver were invited to another room (the eye-tracking lab) where a battery of eye-tracking tasks, including the Non-social Pop Out and the Sustained Attention tasks, was presented to the infant. A detailed description of the study procedure can be found in Chapter 2.

5.2.4. Analytical Approach

5.2.4.1. Analysis plan

Firstly, bivariate correlations were computed to examine whether expected associations between measures supposedly capturing sustained attention and novelty preference could be observed. I expected correlations between the measures I hypothesised would load onto the sustained attention factor (positive between peak look in the array task and peak manual toy exploration, and negative between peak look in single object task and peak manual toy exploration, as well as peak look in the array task), and positive correlations between the measures I hypothesised to load onto the novelty preference factor. If the correlations revealed the expected pattern of results, a two-factor Confirmatory Factor Analysis (CFA) model would be fitted to the data.

A CFA would be conducted to investigate whether the proposed model of two factors, sustained attention and novelty approach, driving the observed differences in infant behaviours in terms of their visual scanning patterns and manual exploration of toys, would fit to our data. I hypothesised that peak look in an array task, peak manual toy exploration, and peak look in the Sustained Attention Task would all load onto a common factor of sustained attention, although the latter would load negatively, consistent with previous literature (Tamis-Lemonda & Bornstein, 1993; Wass et al., 2011). Moreover, I hypothesised that the number of the objects looked at, the number of objects manually explored and the latency to touch a toy would positively load onto a common factor of novelty preference. The factors of sustained attention and novelty preference would be allowed to correlate, possibly sharing variance due to an underlying common factor of general exploratory competence (see Figure 5.2. depicting the hypothesised model).

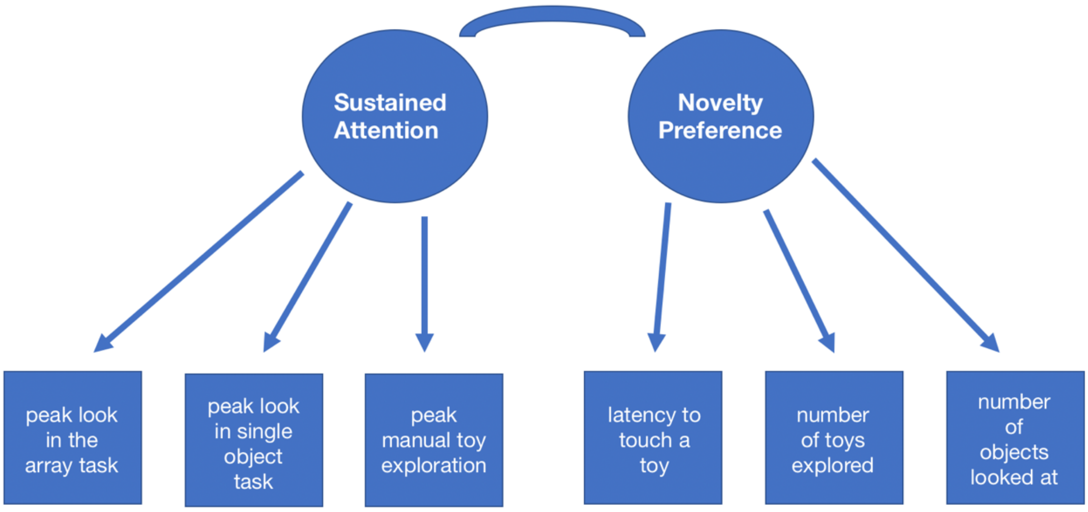

Figure 5.2. The hypothesised two-factor model of exploratory behaviour

5.2.4.2. Video-coding

Videos of the Sequential exploration toy task and the Simultaneous exploration toy task were coded frame by frame using the Datavyu software (Datavyu Team, 2014) at 30 frames per second.

5.2.4.3. Eye-tracking data analysis

Eye-tracking data was analysed using a custom scripts written in MATLAB R2017a. Look target coordinates were calculated from an average of *x* and *y* gaze locations from both eyes; single-eye data points were used where data from one eye was missing. Periods of data loss (due to blinks or temporary inaccuracy of data capture) up to 150 ms were linearly interpolated.

5.3. Results

5.3.1. Descriptive statistics

Sixty-two participants provided latency to touch a toy data in the Sequential exploration toy task (data from 8 participants was missing due to their fussiness making them unable to perform the task; 1 participant's data was not usable due to their caregiver encouraging them and helping them out with the toys). Fifty-four participants contributed peak manual toy exploration and number of toys explored data from the Simultaneous exploration toy task (8 participants were too fussy to perform the task, 1 only completed a little over 60 seconds of it, 4 participants' data was unavailable due to technical problems with the recordings, and finally, there was interference with the task from parents for 3 participants). Sixty-four participants contributed peak look to an object and number of objects looked at data from the Non-social Pop Out task; 53 provided the peak look in the Sustained Attention (SA) task (7 participants did not participate in the eye-tracking session at all due to fussiness, additional 11 did not provide enough data in the SA eye tracking task to yield an adequate measure).

Table 5.1. shows descriptive statistics for: latency to touch a toy, number of toys explored, number of objects looked at, peak toy exploration, peak look in the array task and peak look to a single object.

Within age groups, a series of Shapiro-Wilk tests showed that the variables were normally distributed, with three exceptions: Latency to touch a toy was not normally distributed in the younger group ($W(32) = 0.940$, $p < 0.001$), and in the older group, normality was violated for the number of objects looked at ($W(31) = 0.899$, $p = 0.007$) and peak look in the array task ($W(31) = 0.870$, $p = 0.001$). The distributions of the variables split by age group are shown in Figure 5.3.

Table 5.1. Descriptive statistics for the measures of exploratory behaviour, split by age group

		Minimum	Maximum	Mean	Std. deviation
Latency to touch a toy [s]	6-8 months N = 33	0.39	7.22	1.59	1.30
	11-13 months N = 29	0.84	7.47	2.4	1.80
Number of toys explored	6-8 months N = 27	2	7	4.3	1.3
	11-13 months N = 27	3	9	5.3	1.5
Number of objects looked at	6-8 months N = 33	2	5	3.8	0.7
	11-13 months N = 31	2.3	5	4.2	0.7
Peak toy exploration [s]	6-8 months N = 27	9.2	116.0	55.9	30.00
	11-13 months N = 27	7.3	135.9	50.1	34.20
Peak look in the array task [s]	6-8 months N = 33	0.51	3.94	1.81	0.85
	11-13 months N = 31	0.68	4.46	1.94	0.90
Peak look in the single object task [s]	6-8 months N = 27	4.4	40.0	19.1	9.9
	11-13 months N = 26	5.5	39.5	20.7	10.4

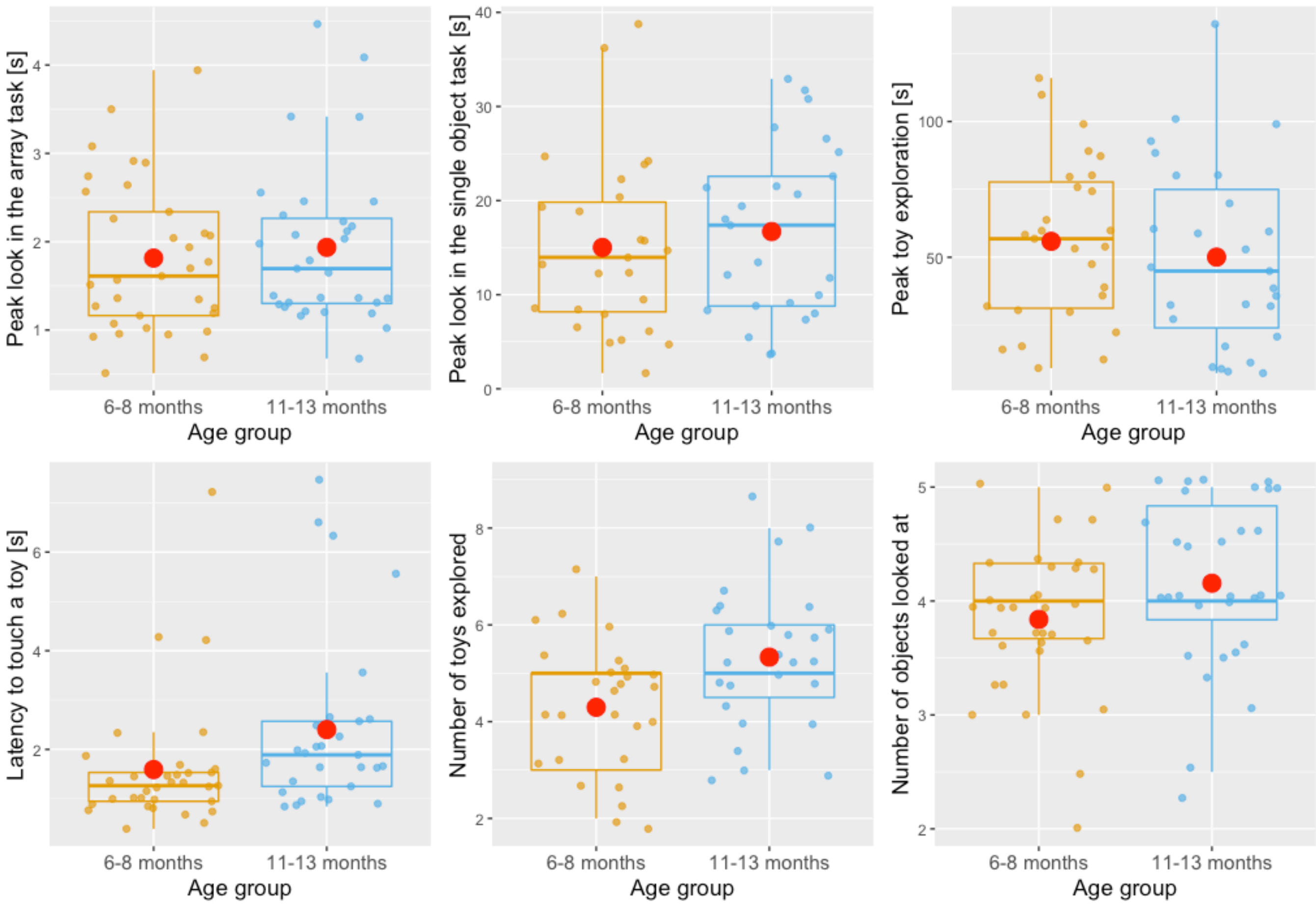

Figure 5.3. Boxplots showing distributions of peak look in the array task (top left), peak look in the single object task (top middle), peak toy exploration (top right), latency to touch a toy (bottom left), number of toys explored (bottom middle) and number of objects looked at (bottom right). All individual data are represented by points. Horizontal lines within boxplots indicate the median value, while red dots represent mean values.

A series of Mann-Whitney tests (where normality assumption was violated) and t-tests (where normality assumption was not violated) was conducted to test the differences between age groups with respect to the six variables of interest. Latency to touch a toy was higher in the older group ($U = 251$, $p = 0.016$), and so was the number of toys explored ($t(52) = -2.65$, $p = 0.011$), although the significance did not reach the Bonferroni-corrected threshold value of $p = 0.008$ (six tests). The age groups did not differ with regard to peak toy exploration ($t(52) = 0.66$, $p = 0.51$), peak look in the single object task ($t(51) = -0.59$, $p = 056$) or peak looks in the array task ($U = 465$, $p = 0.54$). Mean number of objects looked at showed a trend towards being higher in the older group ($U = 373$, $p = 0.059$).

In further analyses, I make the assumption that age would not moderate the investigated relations and therefore pool the data from both age groups together. However, this results in the normality assumption being violated for each one of the six variables, so Spearman correlations between the variables are calculated.

5.3.2. Bivariate correlations

Spearman correlations between the measures are shown in Table 5.2. No correlations reached the Bonferroni-corrected threshold of p-value = 0.008. However, I observed trends towards a positive correlation between peak look in the array task and peak look in the single object task (see Figure 5.4.). Contrary to our hypothesis, I observed negative correlations between peak manual toy exploration and peak look in the array task and peak look in the single object task, although they were not statistically significant. Among the measures hypothesised to capture novelty preference, the correlation between the number of objects looked at and the number of objects explored is positive, although not significant (see Figure 5.4.).

These results suggest that while peak looks observed in visual attention paradigms are stable within an individual, and likely tap into a common underlying factor, peak manual toy exploration is not only not an equivalent measure, but it is even negatively associated with the peak look measures. Meanwhile, both the number of objects looked at and the number of toys explored likely capture a common element – possibly novelty approach, which would be consistent with what was hypothesised.

Table 5.2. Spearman correlations between measures hypothesised to capture sustained attention and novelty preference
p-values not corrected for multiple comparisons

Sustained attention			
		peak look in the single object task	peak manual toy exploration
peak look in the array task	correlation coefficient	0.320	-0.229
	Sig. (2-tailed)	0.021	0.103
	N	52	52
peak look in the single object task	correlation coefficient		-0.243
	Sig. (2-tailed)		0.113
	N		44

Novelty preference			
		number of toys explored	number of objects looked at
latency to touch a toy	correlation coefficient	0.007	-0.108
	Sig. (2-tailed)	0.962	0.444
	N	50	52
number of toys explored	correlation coefficient		0.255
	Sig. (2-tailed)		0.068
	N		52

Since the hypothesised pattern of correlations was not confirmed by our data, an exploratory investigation into the correlations between all six measures was conducted, shown in Table 5.3.

Table 5.3. Spearman correlations between all exploratory behaviour measures p-values not corrected for multiple comparisons

		peak look in the single object task	peak manual toy exploration	peak look in the array task
latency to touch a toy	correlation coefficient	-0.050	-0.059	-0.049
	Sig. (2-tailed)	0.749	0.686	0.729
	N	44	50	52
number of toys explored	correlation coefficient	0.070	-0.241	0.245
	Sig. (2-tailed)	0.651	0.079	0.080
	N	44	54	52
number of objects looked at	correlation coefficient	0.211	0.083	0.309
	Sig. (2-tailed)	0.134	0.557	0.021
	N	52	52	52

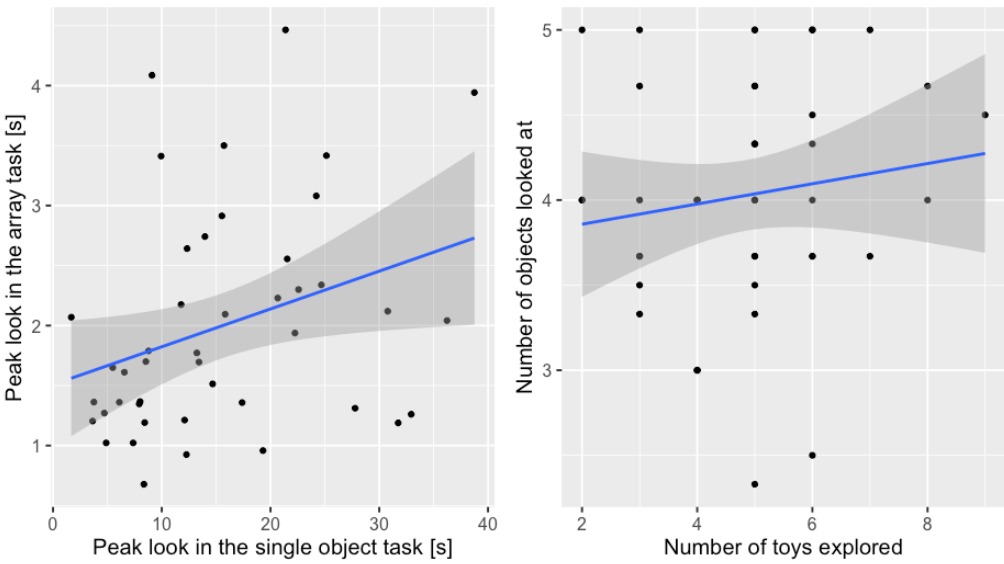

Figure 5.4. Relation between peak look in the single object task and peak look in the array task (left) and number of toys explored and number of objects looked at (right) with fitted regression lines with confidence intervals

While these investigations have to be treated with caution considering the number of comparisons and their exploratory nature, they nevertheless reveal an interesting pattern: while the direction of association between the number of objects looked at and peak look in the array task is positive, the direction of association between the number of toys explored and peak toy exploration is negative, suggesting a possible trade-off between breadth and depth of exploration in the manual toy exploration task. Meanwhile, not only is no such trade-off observed in the visual attention task, but the positive association suggests that there may be a general factor of exploratory competence behind both the depth (peak looks) and breadth (number of toys looked at) of visual exploration. However, it has to be noted that the possible differences may also be due to the degrees of differences between the timings of the tasks, i.e. the durations of presentation of the slides in the visual exploration tasks were measured in tens of seconds, while the durations of object presentation in simultaneous table top manual exploration task – in minutes.

5.3.3. Confirmatory Factor Analysis

As the correlation analysis did not reveal the expected pattern of results consistent with the hypothesised model, Confirmatory Factor Analysis was not conducted on the data.

5.4. Discussion

The aim of the present investigation was to improve our understanding of the associations between two key drivers of exploratory behaviour: *novelty approach* and *sustained attention*. I hypothesised that measures of peak durations of looks or manual exploration derived from manual and visual exploration tasks would load onto a common dimension of sustained attention, while latency to touch a toy, number of toys explored and number of objects looked at would load onto a dimension of novelty approach. However, the data was not consistent with the hypothesised two-factor model.

For measures supposedly capturing sustained attention, it seemed there was an agreement between peak look measures in visual attention paradigms, but there was a negative association with the peak manual toy exploration measure. These findings add to the evidence that peak look measures derived from different screen-based tasks (e.g. static and dynamic) are significantly positively correlated with each other (Wass, 2014), and further extends it to cases where multiple areas of interest within a slide are present. Yet, these results suggest that peak look measures, even with multiple objects (areas of interest) present, possibly represent speed of encoding rather than endogenous control of attention. Thus, it seems that peak looks as measured in eye-tracking/visual attention paradigms are not good indicators of infant attention in multisensory, "real world" exploration, and may be more associated with the efficiency of encoding visual features of an object.

Yet, given the differences in the timing of the screen-based and table top toy exploration tasks (tens of seconds relative to minutes), there is an alternative explanation of the negative association between the peak looks and peak manual exploration. In each continuous manual exploration bout, there were likely several looks to the explored object. It is possible that the longer these looks would be, the more information would be sampled about the object, and the faster the infant would be able to move on to another object. Future studies should examine this possibility with measures of single looks during periods of manual exploration.

I also found that measures hypothesised to capture novelty preference do not show significant associations with each other. The correlation between number of toys explored and number of objects looked at was positive (though not significant). It may be that both these measures are in part driven by a common underlying factor of novelty preference, but this association could have been blurred by e.g. differences in motor skills (which I did not account for). Moreover, it is possible that while latency to touch a toy, a measure closely related with measures of exploration used in animal studies (Guardini et al., 2016; Simpson, Sclafani, et al., 2019), captures the novelty approach aspect of exploratory behaviour, the number of toys explored and the number of objects looked at might tap into a different information sampling aspect. Given that these two measures not only showed a degree of correlation with each other, but also with some of the other measures of exploratory behaviour, it seems that they might be more informative about a general exploratory competence, for instance – efficiency of exploration or information processing, rather than about a motivational aspect of information sampling strategies in infants.

Emerging technologies such as head-mounted eye-trackers should improve our understanding of how visual attention measures relate to manual exploration measures. Specifically, studies on infants' behaviour in their natural, everyday surroundings might be especially informative about the ways they sample information and learn (Slone et al., 2019). Yet, given, how nowadays infants are increasingly exposed to screens – not just computers and television, but also smartphones and tablets, offering interactive engagement - measures derived from visual attention paradigms (stimuli presented on screen) may be more informative about infant cognition than they ever were. However, screen time in early development is also associated with reduced endogenous attention control (Portugal et al., 2021). The topic of infant attention and screen use is a complex one; future studies should ideally incorporate measures of infant screen time as possible moderators of the associations between infant "naturalistic" and screen-based measures of attention.

Given that the hypothesised model with two factors, sustained attention and novelty approach, was not confirmed, I chose not to perform any dimension reduction on the measures of infant exploration. Even though the peak looks in the array and the single object tasks were significantly positively correlated, given that there is little research on the correlates of attention as measured with peak looks in tasks where multiple areas of interest are present, I decided to keep these two measures separate. Following the argument outlined in the introduction to the present chapter, I believe that the peak look in the array task might capture infants' endogenous attention better. Indeed, peak looks in the array task, but not peak looks in the single object tasks, exhibited a trend-level positive correlation with measures I had hypothesised represent novelty approach (number of objects looked at, number of toys explored); this suggests that peak looks in the array task to an extent capture a factor of general exploratory competence. Therefore, in the following chapter where I investigate the association between caregiver touch, infant stress response and exploratory behaviour, I keep the six measures of exploratory behaviour separate.

Chapter 6

Caregiver touch and infant exploratory profile

6.1. Introduction

Previous chapters have dealt with topics essential to the understanding of the putative association between caregiver touch and infant exploratory behaviour. Chapter 3 introduced the various methods employed to capture caregiver touching behaviours, and demonstrated how Self-reported and Observed touch dimensions can be derived from them. Chapter 4 presented evidence from previous research showing that touch affects infant hormonal response in terms of oxytocin and cortisol; however, our own research did not corroborate these findings. Finally, Chapter 5 reported on an investigation into the information sampling mechanisms driving infant exploratory behaviour, novelty approach and sustained attention, showing that screen-based and manual object exploration tasks capture functionally different dimensions of exploratory behaviour. Integrating the findings from these previous chapters with evidence suggesting that tactile stimulation may promote learning in infancy, the current chapter presents an investigation into whether – and how - naturally occurring variation in caregiver touch affects the ways in which infants engage with their environment.

6.1.1. Touch and infant exploratory profile

In Chapter 1, I described the relevant evidence demonstrating links between caregiver touch and arousal, as well as arousal and exploratory behaviours. Yet, the three factors – touch, arousal, and exploratory behaviour – have rarely been studied simultaneously in human infants. The one study which explicitly addressed the hypothesis that touch (specifically – stroking) affects infant visual attention through its effects on heart rate did not find evidence supporting this hypothesis (Pirazzoli, 2019). The findings of Pirazzoli (2019), described in more detail in Chapter 1, indicated that stroking might not affect infant attention. However, the specific measure used in Pirazzoli's study (latencies to reorient to a peripheral stimulus in an eye tracking task) while theoretically motivated as being able to capture the extent to which infant's attention is bottom-up, rather than top-down driven, was a far departure from any measures used in studies on the effects of touch on exploratory behaviour in non-human animal species. Perhaps more straightforward measures which draw from measures used in rodent and macaque studies, like behaviour in response to novel objects, or in a variation of the open field test (Caldji et al., 1998, 2004; Harlow & Zimmermann, 1959; Liu et al., 2000; Simpson, Sclafani, et al., 2019), would be more appropriate for showing the effects of caregiver touch on infant exploratory profile.

Below, I describe one study which attempted exactly that: investigating the effects of caregiver touch on infant behaviour when presented with novel objects. The study is particularly relevant to my research because, although no measures of physiological arousal were collected, it used similar measures of infant exploratory behaviour to the ones I used, and demonstrates some effects of parental touching behaviour on infant exploration.

Hertenstein & Campos (2001) showed that certain types of tactile stimulation provided by the mother might actually hamper exploration of novelty in infants. In this study, 12-month-olds were all sat on their mothers' laps, but assigned to one of three conditions. In one condition, the mothers were asked to hold her infant bilaterally around the torso so that her fingers from both hands interlocked and her thumbs were flat against the infant's abdomen, keeping a steady moderate pressure; this was a control condition. In the second condition, mothers had to rapidly inhale and hold their breath for 1.5 seconds while tightening their grip around the infant's torso; this condition was meant to elicit an increase in tension in infants, and, consequently, hamper exploratory behaviours. The third condition was very similar to the first one, but the grip on the infant's torso was supposed to be lighter[12]; this condition was meant to index mother's relaxed state, elicit a decrease in infants arousal, and promote exploration. While the infants were being

[12] Hertenstein & Campos (2001) trained the mothers before the testing session using a device with an inflatable ball and a manometer, in order to standardise the force with which mothers were holding their infants in each condition.

held by their mothers, they were presented with three toys in front of them, one at a time, for 45 seconds each, while their behaviours were being coded. Hertenstein & Campos (2001) found that in the " tension-increasing" condition, the infants took, on average, 4 seconds longer to touch the novel toys, in comparison with the first, control condition. However, no effects of the "tension-decreasing" condition on latencies to touch novel objects were found – the latencies in this condition did not differ from the latencies in the control condition. Moreover, infants in the "tension-increasing" condition spent significantly less time manually exploring the toys (coincidentally, the difference in the duration of manual exploration between this condition and control condition was also 4 seconds); no effects of the "tension-decreasing" condition on duration of manual exploration were found.

Research published since Hertenstein and Campos' study has shed some more light on these results; it is now clearer why Hertenstein & Campos (2001) failed to detect positive effects of what they meant to be a tension-decreasing condition (with mothers applying light pressure when holding the infants). Studies on massage therapy have found that touch applied with light pressure is not effective in terms of stress reduction; moderate pressure[13] is necessary for its beneficial effects in adults (Diego et al., 2004; Field et al., 2010) and premature infants (Field et al., 2006). Even though massage is a more active form of touch than holding, some researchers have proposed that similar effects of pressure should be found for static touch (Case et al., 2020). Thus, if Hertenstein & Campos's (2001) study was done today, the hypothesis that lighter, rather than moderate pressure, would have calming effects on infants would have been unfounded.

Regarding the effects of the "tension-increasing" condition on infant exploratory behaviour, there are several things to consider. Firstly, it could be argued that the arbitrarily defined type of stimulation applied in this condition, with the mother tightening and loosening her grip on

[13] However, what constitutes "moderate" or "light" pressure is hard to precisely define; e.g. Field et al. (2006) used indentations in infants' skin as a marker of pressure, while Hertenstein and Campos (2001) referred to predefined thresholds shown on the manometer device attached to the inflated ball the mothers were trained on.

the infant while breathing rapidly, was not ecologically valid (the authors claimed otherwise – but did not provide support for this claim). It is difficult to say whether mothers' behaviour in this condition negatively affected infants exploration because that is how mothers would typically behave in circumstances when infants' environment would not be safe to explore, or if mothers' behaviour itself was just unusual and strange, and potentially stressful for infants. Secondly, the fact that the tactile stimulation was paired with unnatural alteration of mothers' breathing, not only could have caused movement due to potential exaggerated mobility in mothers' chest and abdomen, but could have also resulted in breathing sounds adding auditory cues to the tactile (and, potentially, proprioceptive) cues. With layers of possible differences between the control and the "tension-increasing" condition, it is hard to pin down exactly what caused the infants to decrease their exploration, both in terms of novelty approach, as well as duration of manual exploration. Moreover, all three experimental conditions involved caregiver holding the infant on their lap, so no conclusions about the effects of touch relative to no touch can be drawn. Nevertheless, Hertenstein & Campos's (2001) study provided interesting evidence that caregiver can affect their infant's engagement with novel objects through non-visual and non-speech cues.

The studies by Pirazzoli (2019) and Hertenstein & Campos (2001) are rare examples of research addressing the possibility that caregiver touch might alter the infant's exploratory profile. Pirazzoli investigated this possibility in 6 – 10-month olds, Hertenstein & Campos – in 12-month-olds. There were several other differences between the set-up of the two studies, but one of the things they had in common was that they examined the immediate effects of touch on infants' behaviour, i.e. the touch stimulus was happening at the same time as infant's exposure to the novel stimuli.

Yet, in addition to the potential immediate effects of touch on infant exploratory profile, there is evidence pointing to the possibility that caregiver touch could shape infant exploratory profile long-term, through modulating HPA-axis activity (which I reviewed in detail in Chapter 1). No study to date has explicitly addressed that.

My aim in the present study is to investigate the potential long-term effects of caregiver touch on how infants approach novelty and sustain their attention on novel objects, while also looking at possible short-term effects. The various measures of caregiver touch collected in the present study, as discussed in Chapter 3, allow for making inferences about caregiver touch both in terms of its habitual, repetitive everyday patterns, while also providing information about touch happening during the testing session, shortly before performing the exploratory tasks.

6.1.2. Present study

In the present study, I aimed to address the question of whether caregiver touch predicts the ways in which infants engage with their environment in terms of their novelty approach and sustained attention. Firstly, I hypothesise that infants who receive more touch from their caregivers would exhibit more novelty approach; this would be a consequence of experiencing less stress (regulated HPA-axis activity) due to the buffering effects of caregiver touch, and therefore developing an exploratory behavioural profile prioritising novelty over familiarity (or, exploration over exploitation). Secondly, I hypothesise that infants who receive more touch from their caregivers would exhibit a higher ability to sustain attention; this would, again, be a consequence of the effects of touch on the HPA-axis activity, and, therefore, their attentional profile which would be more top-down (vs. bottom-up) driven. These hypotheses are based on putative long-term effects of touch on HPA-axis activity, and, consequently, infant exploratory behaviour (see Figure 6.1.). However, I also hypothesise that analogous effects could be observed for touch during the session, shortly before infants perform the tasks, through caregiver touch affecting infant arousal for a short while.

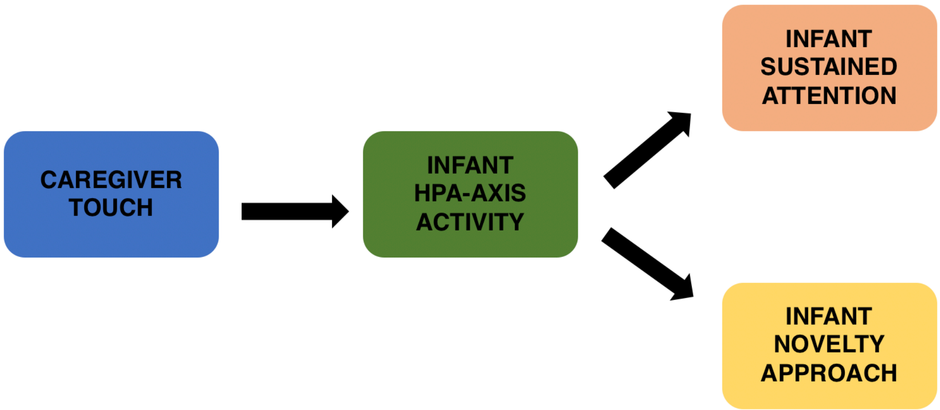

Figure 6.1. Model of the hypothesised effects of caregiver touch on infant exploratory behaviour, mediated by HPA-axis activity

In Chapter 5, I showed that the measures collected in this study, which were originally intended to capture novelty approach and sustained attention, did not exhibit the hypothesised associations in our sample, meaning that they potentially capture different aspects of these two drivers of exploratory behaviour. Therefore, the six measures are treated as independent indicators of what I assume to be different aspects of novelty approach (*Latency to touch a toy, Number of explored toys and Number of objects looked at*) and sustained attention (*Peak toy exploration, Peak look in the array task and Peak look in the single object task*).

In Chapter 3, I presented an analysis demonstrating that the different measures of caregiver touch used in the current study, when combined, yield two dimensions: I labelled them as Self-reported and Observed touch. While this is the main interpretation of the dimensions, and I will refer to these dimensions as Self-reported and Observed touch going forward, they also differ in that the Self-reported touch dimension mostly built on measures capturing affective touch, while the Observed touch dimension – measures of functional, instrumental touch. This is not merely a confounding factor, but rather a consequence of what, I believe, self-reported and observed measures are better at capturing (as I argued in Chapter 3). In order to explore the possible short-term contributions of affective touch (in addition to the Self-reported and Observed touch dimensions), I conduct an investigation into the associations between the five types of touch most commonly used during the session (hugging/holding/cradling, stroking/caressing, moving limbs/body, kissing/patting and static touch) and measures of infant exploratory behaviour. Importantly, the current study differs from the previous studies on this topic (Hertenstein & Campos, 2001; Pirazzoli, 2019) in that it does not include any experimental manipulation of parental touch; instead the aim here was to capture naturally occurring variation in parental touching behaviours.

In Chapter 4, I found that caregiver touch did not predict infant hormonal response as measured with either oxytocin or cortisol. In the present chapter, the focus is on the HPA-axis activity, and therefore the measure of interest is cortisol. Even though caregiver touch did not predict infant cortisol levels, there is a possibility that the effects of caregiver touch would be present in other measures associated with HPA-axis activity, not captured in this study (e.g. heart rate, norepinephrine), therefore associations between caregiver touch and measures of infant exploration are still investigated, based on the same HPA-axis activity mediation hypothesis. Moreover, there is a possibility that cortisol would predict infant exploratory behaviour independently from caregiver touch, which is why I also included this measure. Specifically, I choose to include CORT2 – cortisol measure at the second timepoint – in the analyses, because this measure was collected shortly before the table top-based and eye tracking tasks, and therefore had the potential of capturing infant arousal closest in time to when they completed these tasks.

6.2. Methods

6.2.1. Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in more detail in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and 18 females) and 11- to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females) and their primary caregivers.

6.2.2. Measures

The measures of infant arousal and exploratory behaviour used in the current study have been described in detail in Chapter 4 (Caregiver touch and infant hormonal response) as well as Chapter 5 (Comparing measures of infant information sampling strategies). Table 6.1. shows the measures used in the analyses in the present study together with the number of available data points per measure.

In additional exploratory analyses into the associations between different types of touch employed during the session and infant exploratory behaviours, total duration of hugging/holding/cradling, stroking/caressing, kissing/patting, moving limbs/body and static touch were summed across the two parent-child interaction conditions: PCI-FP (free play) and PCI-Q (conversation with the experimenter). Sixty-six infants provided data for these five measures.

Table 6.1. Measures of caregiver touch, infant arousal and infant exploratory behaviour included in the analyses

Caregiver touch	Infant arousal	Infant exploratory behaviour
PCA Dimension 1: Self-reported caregiver touch (n = 71)	CORT2: cortisol measured at T2 (n = 48)	Latency to touch a toy (n = 62)
PCA Dimension 2: Observed caregiver touch (n = 71)		Number of toys explored (n = 54)
		Number of objects looked at (n = 64)
		Peak toy exploration (n = 54)
		Peak look in the array task (n = 64)
		Peak look in the single object task (n = 53)

6.2.3. Procedure

All measures were collected during the dyad's single visit to the lab, as outlined in detail in Chapter 2. To briefly recap the procedure: at the beginning of the visit, two saliva samples were collected from the infant for oxytocin and cortisol at timepoint one (OT1 and CORT1, respectively). Following a period lasting about 40-minutes, during which parent-infant interactions were coded, saliva samples were collected again for OT2 and CORT2. Then, the infant was presented with table top toy exploration tasks, while being filmed. The first task was the Sequential Object Exploration Task, followed by the Simultaneous Object Exploration Task. During the table top toy exploration tasks, infants were sat in a high chair, thus precluding any momentary influences of parental touch; parents were also asked not to encourage, help or otherwise interrupt infant exploration of objects. After the table top tasks, the infant and their caregiver were invited to another room (the eye-tracking lab) where a battery of eye-tracking tasks, including the Non-social Pop Out and the Sustained Attention tasks, was presented to the infant. During the eye tracking task battery, infants were sat in a car seat, which was placed on parent's lap; no direct tactile contact between the infant and the parent was possible. At the very end of the visit, the caregiver was given the PICTS and STQ questionnaires, and asked to complete the Touch Diary for 7 consecutive days after the visit took place, at home.

6.2.4. Analytical Approach

A series of linear regression models predicting the three measures of novelty approach and three measures of sustained attention with the two dimensions yielded by the PCA, representing Self-reported touch and Observed touch (as described in Chapter 3), and controlling for infant age were performed. As the CORT2 values were not available for all participants, separate linear regression models with the CORT2 added as a predictor to the PCA1, PCA2 and infant age independent variables were performed using the data from the subset of infants with CORT2 values available (n = 48). A further exploratory investigation into potential moderating effects of age group was conducted by means of visual inspection of the regression plots showing the confidence intervals around the regression lines. Additionally, an exploration of Spearman's rho correlations between the five types of touch most commonly employed during the session and the six measures of infant exploratory behaviours was performed.

6.3. Results

6.3.1. Descriptive statistics

Detailed descriptive statistics on all the variables used in the present study are available in Chapters 3, 4 and 5, in Tables 3.1., 3.2., 4.2, and 5.1.

6.3.2. Linear regression analysis

Twelve linear regression models were fitted to the data; six aimed to predict the six exploratory behaviour measures of interest: *Latency to touch a toy, Number of toys explored, Number of objects looked at, Peak toy exploration, Peak look in the array task* and *Peak look in the single object* with Self-reported touch, Observed touch, and infant age as independent variables in the regressions. An additional six models were fitted with CORT2 added as an additional independent variable, but only including the participants for whom CORT2 data was available,.

Detailed statistics on the fitted models can be found in Figure 6.2. I use an uncorrected value of $p = 0.05$ as a cut-off for highlighting potentially meaningful models/associations, although they should not necessarily be treated as statistically significant, given the large number of models fitted and parameters estimated[14]. Only two models passed this threshold.

The model predicting *Number of explored toys* was one of the two models with p-value < 0.05 (model E in Figure 6.2.; $F(3,50) = 0.663$, $p = 0.02$, $R^2 = 0.178$), explaining 17.8% of the variance. However, the only predictor passing the 0.05 threshold was *infant age* ($\beta = 0.44$, $t = 3.119$,

[14] Although, as pointed out e.g. by Cohen (1990), there are arguments against making strict "yes or no" decisions based on the (corrected or uncorrected) p < 0.05 threshold; "*A successful piece of research doesn't conclusively settle an issue, it just makes some theoretical proposition to some degree more likely. Only successful future replication in the same and different settings (as might be found through meta-analysis) provides an approach to settling the issue.*" (Cohen, 1990, p. 1311)

$p = 0.003$), indicating that the older the infants were, the more toys they explored manually; this result makes sense, but is not relevant to the hypotheses in the present study.

The other model passing the $p = 0.05$ threshold was the model predicting *Number of objects looked at* (model I in Figure 6.2.; $F(3, 60) = 3.035$, $p = 0.036$, $R^2 = 0.132$), explaining 13.2% of the variance. In this model, *infant age* passed the $p < 0.05$ threshold ($\beta = 0.33$, $t = 2.51$, $p = 0.015$), while *Self-reported touch* was close to passing the threshold ($\beta = 0.23$, $t = 1.86$, $p = 0.067$). This indicates that the older the infants were, the more objects they looked at – which, even though it is not relevant to the main focus of the present study, suggests a developmental consistency between the two measures of novelty approach (*Number of explored toys*, and *Number of objects looked at*). Moreover, it hints at a possibility that long-term patterns of caregiver affective touch could predict the number of objects looked at, although this association is far too weak to provide conclusive evidence for this.

(A)

Predicting Latency to touch a toy with Self-reported Touch and Observed touch, controlling for age

$F(3, 53) = 0.663, p = 0.579, R^2 = 0.036$

Variable	Standardized beta	t	p
age (days)	0.193	1.29	0.202
Affective Touch	-0.02	-0.15	0.883
Non-affective Touch	0.028	0.19	0.851

(B)

Predicting Latency to touch a toy with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 36) = 0.533, p = 0.712, R^2 = 0.056$

Variable	Standardized beta	t	p
age (days)	0.14	0.71	0.485
cort2	-0.084	-0.48	0.637
Affective Touch	-0.08	-0.48	0.636
Non-affective Touch	-0.043	-0.24	0.812

(C)

Predicting Peak toy exploration with Self-reported Touch and Observed touch, controlling for age

$F(3, 50) = 0.564, p = 0.641, R^2 = 0.033$

Variable	Standardized beta	t	p
age (days)	-0.123	-0.81	0.424
Affective Touch	-0.151	-1.06	0.296
Non-affective Touch	-0.126	-0.83	0.408

(D)

Predicting Peak toy exploration with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 36) = 0.246, p = 0.910, R^2 = 0.027$

Variable	Standardized beta	t	p
age (days)	0.126	0.63	0.53
cort2	0.123	0.68	0.499
Affective Touch	-0.069	-0.4	0.689
Non-affective Touch	-0.001	-0.01	0.994

(E)

Predicting Number of explored toys with Self-reported Touch and Observed touch, controlling for age

$F(3, 50) = 0.663, p = 0.02, R^2 = 0.178$

Variable	Standardized beta	t	p
age (days)	0.439	3.119	0.003
Affective Touch	0.05	0.364	0.717
Non-affective Touch	0.036	0.258	0.798

(F)

Predicting Number of explored toys with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 36) = 1.02, p = 0.410, R^2 = 0.102$

Variable	Standardized beta	t	p
age (days)	0.35	1.832	0.075
cort2	0.004	0.026	0.979
Affective Touch	0.07	0.43	0.67
Non-affective Touch	0.067	0.391	0.698

(G)

Predicting Peak look in the array task with Self-reported Touch and Observed touch, controlling for age

$F(3, 60) = 0.739, p = 0.533, R^2 = 0.036$

Variable	Standardized beta	t	p
age (days)	0.199	1.454	0.151
Affective Touch	0.002	0.017	0.987
Non-affective Touch	0.102	0.743	0.461

(H)

Predicting Peak look in the array task with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 38) = 1.164, p = 0.342, R^2 = 0.109$

Variable	Standardized beta	t	p
age (days)	0.259	1.437	0.159
cort2	-0.017	-0.1	0.92
Affective Touch	0.197	1.25	0.219
Non-affective Touch	0.272	1.615	0.115

(I)

Predicting Number of objects looked at with Self-reported Touch and Observed touch, controlling for age

$F(3, 60) = 3.035, p = 0.036, R^2 = 0.132$

Variable	Standardized beta	t	p
age (days)	0.326	2.51	0.015
Affective Touch	0.228	1.86	0.067
Non-affective Touch	0.056	0.43	0.671

(J)

Predicting Number of objects looked at with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 38) = 1.811, p = 0.147, R^2 = 0.160$

Variable	Standardized beta	t	p
age (days)	0.272	1.55	0.129
cort2	0.081	0.5	0.618
Affective Touch	0.347	2.27	0.029
Non-affective Touch	0.266	1.63	0.111

(K)

Predicting Peak look in the single object task with Self-reported Touch and Observed touch, controlling for age

$F(3, 49) = 0.689, p = 0.563, R^2 = 0.040$

Variable	Standardized beta	t	p
age (days)	0.107	0.73	0.471
Affective Touch	0.124	0.84	0.403
Non-affective Touch	0.102	0.74	0.461

(L)

Predicting Peak look in the single object task with Self-reported Touch, Observed touch and Cort2, controlling for age

$F(4, 33) = 0.819, p = 0.522, R^2 = 0.090$

Variable	Standardized beta	t	p
age (days)	0.247	1.2	0.238
cort2	0.161	0.85	0.402
Affective Touch	-0.073	-0.43	0.672
Non-affective Touch	0.26	1.42	0.164

Figure 6.2. Results of the linear regression models predicting Latency to touch a toy, Number of toys explored, Number of objects looked at, Peak toy exploration, Peak look in the array task and Peak look in the single object task with Self-reported touch, Observed touch controlling for age, and with Cort2 as an additional predictor

6.3.3. Age group effects

These initial analyses were followed up with an exploration of any potential age group effects on the investigated relations between touch measures and measures of novelty approach and sustained attention. Specifically, I was interested in if *Self-reported* or *Observed touch* associations with infant exploration would differ between infants who need to rely on their parents physical assistance (6-8-month-olds) for exploration, and infants with more gross motor independence (11-13-month-olds). To this end, Figures 6.3 and 6.4 show regression lines with confidence intervals for the measures of novelty approach and sustained attention predicted by *Self-reported touch* and *Observed* touch respectively, split by age groups.

Based on a visual inspection of the plots, I infer that there may be an effect of *Self-reported touch* on the *Number of objects looked at* (top right plot in Figure 6.3), moderated by age group: with a positive association in the older group, and no association in the younger group (however, ANCOVA revealed that the interaction was not significant; $F(1, 60) = 2.32$, $p = .13$, partial $\eta 2 = .037$). Still, considering that, as discussed above, the regression analysis revealed an association between *Self-reported touch* and *Number of objects looked at* which was close to passing the conventional, uncorrected p-value level of $p < 0.05$ ($\beta = 0.23$, $t = 1.86$, $p = 0.067$), it seems that this association was largely driven by the older group.

The association between *Observed touch* and *Latency to touch a toy* (top left plot in Figure 6.4) also seems to be moderated by age group, with the older infants exhibiting longer latencies to touch a novel object the more observed touch they receive, but the younger ones not showing such association (ANCOVA revealed that the interaction was not quite significant; $F(1, 53) = 3.11$, $p = .083$, partial $\eta 2 = .055$). This association is not consistent with the hypotheses of the study (touch leading to increased, rather than decreased approach of novelty), and is likely to be spurious given the large number of associations investigated.

No other plots revealed any evident interactions with age group.

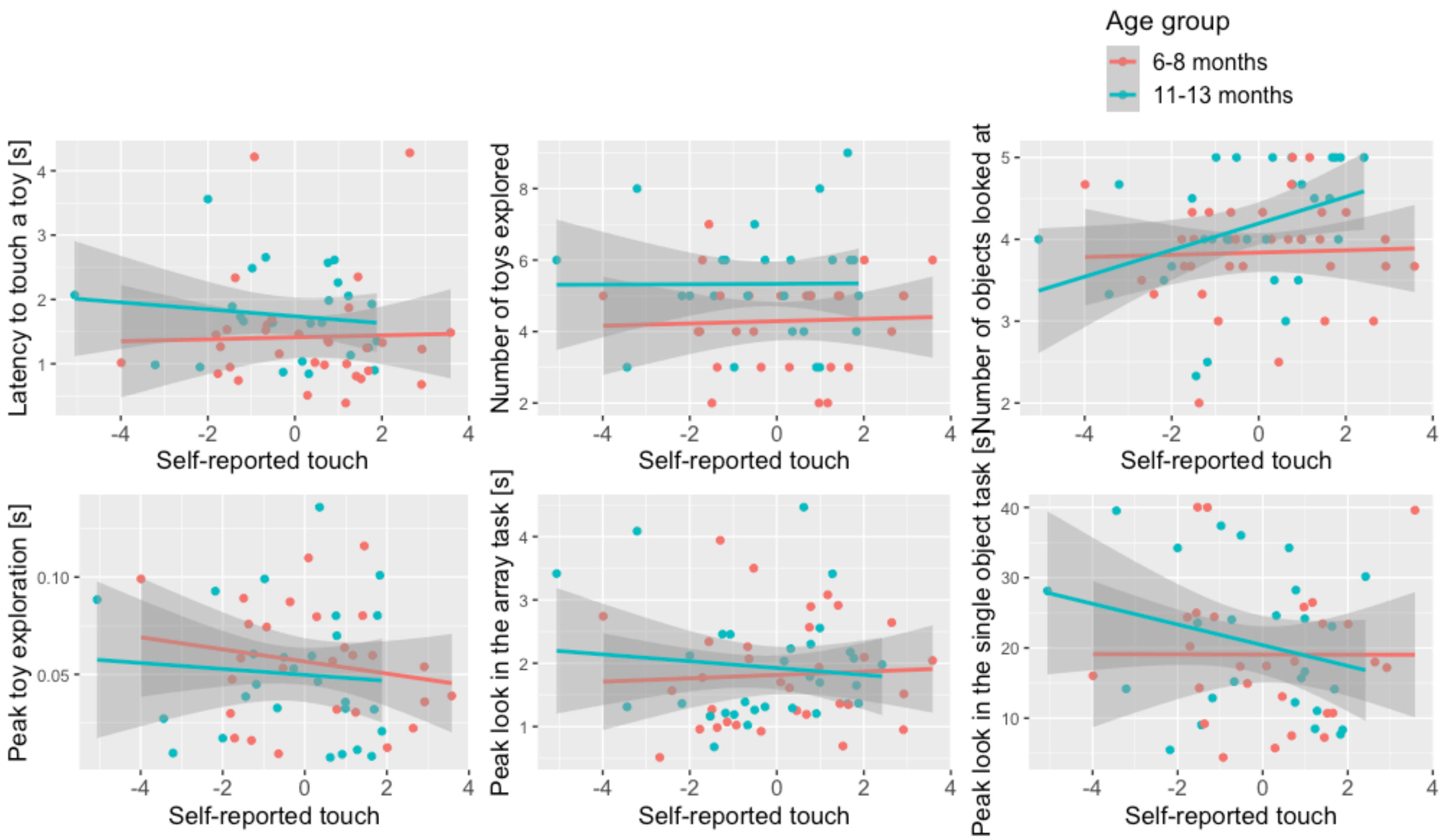

Figure 6.3. Scatterplots showing the relation between Self-reported touch scores and Latency to touch a toy (top left), Number of toys explored (top middle), Number of objects looked at (top right), Peak toy exploration (bottom left), Peak look in the array task (bottom middle) and Peak look in the single object task (bottom right) split by age group, with fitted linear regression lines with confidence intervals

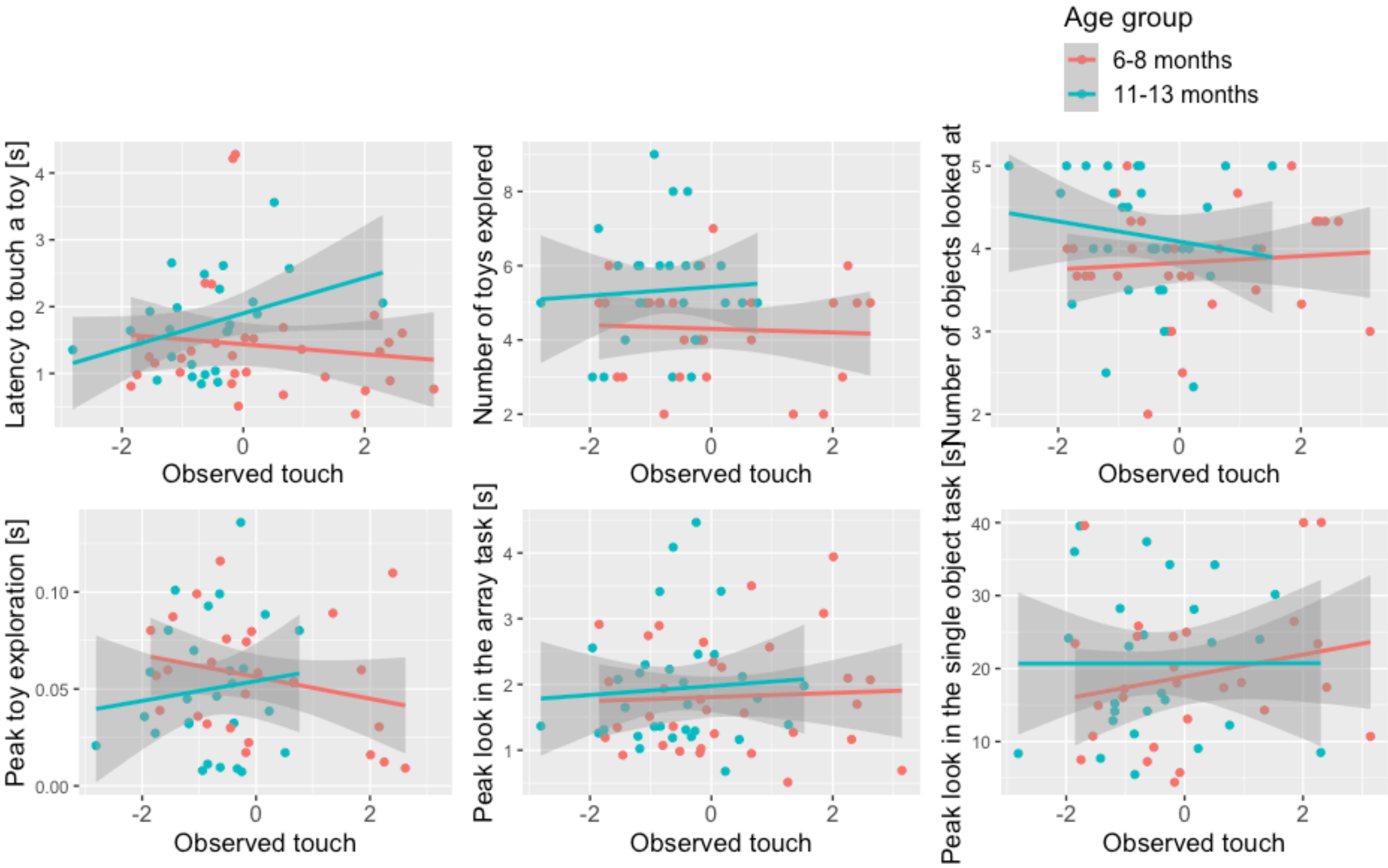

Figure 6.4. Scatterplots showing the relation between Observed touch and Latency to touch a toy (top left), Number of toys explored (top middle), Number of objects looked at (top right), Peak toy exploration (bottom left), Peak look in the array task (bottom middle) and Peak look in the single object task (bottom right) split by age group, with fitted linear regression lines with confidence intervals

6.3.4. Correlations between types of touch and measures of infant exploration

A series of Spearman's rho correlations between the durations of five types of touch most commonly employed during the parent-child interactions was conducted in order to explore if any particular types of affective touch showed associations with infants exploration in the data pooled together from all infants (as the previous analyses indicated that interactions of caregiver touch with infant age were unlikely). If such associations would be present, it would point towards the possibility of specific types of affective touch influencing infant engagement with novelty short-term. These correlations are shown in Table 6.2.

Using an uncorrected $p < 0.05$ threshold to highlight potentially significant correlations, *stroking/caressing* seems to be positively correlated with *Peak look in the single object task* ($r_s(49) = 0.32$, $p = 0.025$), indicating that the more stroking and caressing the infant received from the caregiver during the parent-child interactions preceding the exploratory tasks, the longer were their longest looks, when presented with a single, complex object. None of the other types of touch came close to being correlated with *Peak look in the single object task*, or any other sustained attention or novelty approach measures, for that matter. This finding possibly speaks in favour of the distinctiveness of stroking (or, C-tactile touch) in affecting infant sustained attention, albeit only in terms of attention to a single complex stimulus.

Table 6.2. Spearman's rho correlations between most commonly employed types of touch and measures of infant exploratory behaviour; p-values not corrected for multiple comparisons

		hug/hold/cradle	stroke/caress	moving limbs/body	kiss/pat	static
Peak look in the array task	**correlation coefficient**	0.056	-0.042	0.174	0.209	0.144
	Sig. (2-tailed)	0.67	0.747	0.179	0.106	0.268
	N	61	61	61	61	61
Peak look in the single object task	**correlation coefficient**	-0.028	0.321	0.177	-0.123	0.208
	Sig. (2-tailed)	0.849	0.025	0.224	0.398	0.151
	N	49	49	49	49	49
Peak toy exploration	**correlation coefficient**	-0.088	-0.138	-0.028	0.093	-0.201
	Sig. (2-tailed)	0.537	0.328	0.842	0.51	0.154
	N	52	52	52	52	52
Latency to touch a toy	**correlation coefficient**	-0.114	-0.084	-0.137	-0.099	-0.166
	Sig. (2-tailed)	0.423	0.554	0.334	0.483	0.24
	N	52	52	52	52	52
Number of toys explored	**correlation coefficient**	-0.046	0.107	-0.002	-0.069	0.062
	Sig. (2-tailed)	0.747	0.448	0.989	0.626	0.663
	N	52	52	52	52	52
Number of objects looked at	**correlation coefficient**	0.014	0.046	0.247	0.226	0.04
	Sig. (2-tailed)	0.916	0.725	0.055	0.080	0.76
	N	61	61	61	61	61

6.4. Discussion

In the present study, long-term and short-term effects of naturally occurring variation in caregiver touch on infant behaviour were investigated, with the hypothesis that more touch would lead to developing an exploratory profile prioritising novelty over familiarity, but also promoting sustained (vs. vigilant) attention. Moreover, touch received during the session could also affect infant arousal and, in turn, behaviour during that session. I did not find much evidence for this hypothesis.

Using the two dimensions derived from the collection of caregiver touch measures, Self-reported touch and Observed touch, as predictors of measures of infant sustained attention and novelty approach, none of the hypothesised relations were significant. However, there was weak evidence that the Self-reported touch dimension might promote novelty approach in terms of the number of objects an infant looked at when presented with multiple objects on a screen, which was more pronounced in the older group (11 to 13 months). The Self-reported touch dimension represents types of touch employed in playful, infant-focused interactions, and captures parental long-term touching patterns. It would seem that infants who receive more of this type of touch might be more drawn to visual novelty; however, there was no association between infant cortisol and the number of objects looked at. Given that it is not a well-established measure of novelty approach, and that no other associations between Self-reported and Observed touch dimensions and measures of novelty approach were found, this result is does not strongly support the original hypothesis.

An investigation into the associations between types of affective touch used by caregivers during parent-child interactions and the measures of sustained attention and novelty approach (which were collected after the interactions) did not point to one particular type of touch as systematically related with infant exploratory profile. Stroking was correlated with infant's duration of looking to a single object, but not with any other measures. This indicates that C-tactile targeted touch might affect some aspects of sustained attention, though, interestingly, parents employed around 6 seconds of stroking during 5 minutes of interaction (see Chapter 3). Would such amounts of stroking be enough to affect infant attention, as measured 10 to 20 minutes later? In a study with macaque monkeys, 5 minutes of stroking affected monkeys' attention to social, relative to non-social stimuli when measured immediately afterwards (Simpson, Maylott, et al., 2019); it is unclear if such effects would have been observed with a shorter period of stroking, or a longer delay between stroking and the task (although, arguably, the mechanism behind touch and infant attention in the study by Simpson, Maylott at al. (2019) might differ from the effects of touch on arousal, as I discuss in Chapter 7). Or rather, did the stroking I observed during the PCIs capture parental everyday stroking behaviours, even though the analysis presented in Chapter 3 would suggest otherwise? The association between stroking and infant sustained attention would have to be replicated, ideally in an experiment similar to the one conducted by Pirazzoli (2019).

Besides obvious differences between the current study and the study by Pirazzoli (2019), like correlational, compared to experimental design, and different measures of attention, C-tactile targeted touch (and all other types of coded touch) in the present study was observed and quantified some 10 to 20 minutes before the infants performed the exploratory tasks. It is possible that by the time the infants were presented with the tasks, any effects of touch would have worn off. If this was the case, then we would have expected for touch to correlate with the measures taken chronologically earlier (here, that would be the measures derived from the table top exploratory tasks, i.e. latency to touch a toy, peak toy exploration and number of toys explored), and the correlation to weaken or disappear with the measures taken later. However, the only seemingly significant correlation was observed with peak looks to a single object, which was a measure taken relatively late after the parent-child interaction. Yet, as I observed in Chapter 5, the measures collected in the object-exploration tasks and eye tracking tasks are not equivalent, and likely represent different aspects of sustained attention and novelty preference; thus, any speculations about the timing of the effects in the current study are confounded by the differences between the measures. Future studies might benefit from counterbalancing the order of different tasks in order to investigate both the associations between touch and measures of exploratory behaviour, as well as the timing of these effects.

It is possible that while touch has the potential to modulate infant arousal instantaneously, and therefore possibly affect infant engagement with the environment on a short-term basis, it does not lead to more established changes in exploratory profile. However, whether touch can affect infant attention in short-term is also not evident, as, to the best of my knowledge, the only attempt to investigate this failed to detect immediate effects of touch on infant attention (Pirazzoli, 2019).

Alternatively, the effects of caregiver touch on infant exploratory profile may be delayed in time. Feldman et al. (2014) found that Kangaroo Care intervention in the neonatal period had a modest effect on infant Mental Development Index at 6 months, which became more robust at 12 months.[15] This is perhaps why in the present study, I only observed some preliminary weak evidence for Self-reported touch being positively associated with Number of objects looked at in the older group (but not younger group); given how in Chapter 3 I demonstrated that the Self-reported touch dimension, in contrast to the Observed touch dimension, does not correlate with age, it could have captured the amount of affective touch the infants had been receiving throughout their development. Thus, this speaks in favour of the delay in effects of caregiver touch on infant exploratory profile, however it has to be stressed that the evidence in the present study is not strong, and only pertains to a single measure of interest. More research, and ideally – longitudinal studies are needed to further examine this hypothesis.

It is also possible that the effects of touch on infant HPA-axis activity, and, consequently, exploration, are only present under rather extreme circumstances (e.g. in case of infants born

[15] At 6 months, the MDI scores were 96.09 (SD = 6.75) in the Kangaroo Care (KC) group and 93.25 (SD = 8.26) in the control group ($F_{2,111} = 4.04$, $p = 0.047$); at 12 months, the MDI scores were 91.33 (SD = 8.13) in the KC group, and 84.96 (SD = 10.59) in the control group ($F_{2,111} = 12.94$, $p < 0.001$)

prematurely or raised in families experiencing poverty). The role of caregiver touch may be to protect against adverse effects of intense early stress, but its beneficial effects may be weak or non-existent under "typical" circumstances. Given some reports showing that touch buffered against adverse effects of maternal depression in infancy, but did not have direct effects on infant measures of emotional regulation (Pickles et al., 2017; Sharp et al., 2015; Sharp et al., 2012), it is possible that I did not observe any robust effects of caregiver touch in the present study because the sample consisted of full-term infants, and no specific inclusion criteria of early adversity were present in the recruitment process.[16]

I also did not find evidence that infant arousal, as measured with salivary cortisol, would predict infant novelty approach and sustained attention. This may indicate that while basal cortisol may be a good index of infant HPA-axis activity on a longer time scale (Finegood et al., 2017), a single measurement does not capture the dynamic changes in arousal needed to predict infant behaviour. There is evidence that infant attention and engagement with the environment is dynamically modulated by arousal on a short timescale (i.e. matters of tens of seconds rather than minutes; de Barbaro et al., 2017). Measures allowing for more frequent sampling/higher time resolution (e.g. heart rate, electrodermal response) might be more suited for studying arousal – behaviour effects in infancy.

In the next chapter I explore the associations between caregiver touch, oxytocin and infant attention to faces.

[16] Although, unfortunately, I did not collect data on family socioeconomic status or parental depression.

Chapter 7

Caregiver touch and infant attention to faces

7.1. Introduction

The previous chapter described investigations into the role of caregiver touch in shaping broadly-defined exploratory behaviour in infancy, focusing on infant response to non-social stimuli. However, there are reasons to think that caregiver touch can affect infant response to social stimuli in a way which goes beyond its general effects on information sampling strategies. Although the specifically *social* functions that touch serves in infancy have been recognised and, to an extent, investigated for decades (e.g. Hertenstein, 2002; Stack & Muir, 1990), recent years have seen particularly increased interest in this avenue of inquiry (e.g. Della Longa et al., 2017, 2020; Nava et al., 2020; Provenzi et al., 2020; Reece et al., 2016). In this Chapter, I will review the recent research relevant to the topic of caregiver touch and infant social orienting and learning, and describe the putative mechanisms driving this association. I will also present the results of a study investigating the association between caregiver touch and infant attention to faces.

7.1.1. Caregiver touch and social orienting/learning

Evidence for caregiver touch being associated with social orienting and learning in infants and young children comes from both correlational and experimental studies. Naturally occurring variation in caregiver touching patterns, as observed during a play session, was found to correlate with attention to social stimuli in 4- to 6-year-old children (Reece et al., 2016); those children who were touched more frequently by their mothers during the play session were more distracted by faces (relative to non-social stimuli – houses) in an object categorization task, i.e. when performing a on object-categorization task where the target stimuli were overlaid on pictures of faces or houses, their responses were on average less accurate with face pictures (vs. house pictures) in the background. This finding suggests that receiving more touch from the caregiver is associated with increased social orienting, i.e. children's attention being more drawn to social vs. non-social stimuli.

In contrast, in late childhood and early adolescence (ages 8 to 14 years), parental touch before performing a task measuring attention to social threat (threating facial expressions) reduced children's attention towards socially threatening stimuli (Brummelman et al., 2018). These findings demonstrate that parental touch in childhood might modulate the child's attention towards social stimuli, possibly promoting a flexible attentional response depending on the context.

These results point to the effects of touch on social attention in development, which seem to be distinct from the putative effects of touch on general attention, discussed in the previous chapter. Moreover, these effects seem to be present early: recent experimental studies have shown that touch modulates response to social stimuli in infants as young as 4 months (Della Longa et al., 2017; Nava et al., 2020).

Nava et al. (2020) found that stroking (but not tapping) performed by an unfamiliar experimenter seated next to the infant decreased electrodermal response (an index of arousal) to face stimuli, but not non-social (house) stimuli in 4-month-olds. This finding not only corroborates the existence of specifically social effects of affective touch, but by showing that even tactile stimulation provided by a stranger can cause these effects, it seems to support the notion of these effects being bottom-up (although, arguably, the fact that touch was being delivered by a person and not e.g. a robot could have been relevant in the context of potential top-down effects). However, even though the touching stimulation was delivered to the infant by a stranger sitting next to them, it is not clear if there was no possibility that the infant believed it was actually delivered by their caregiver. This is an important caveat, as it was shown that an experimental manipulation causing infants to believe that a touching stimulation was performed by their caregiver, even though it was performed by an unfamiliar experimenter, had an effect on heart rate in 9-month-olds: a deceleration in a CT-optimal condition was only present in the "pretend" caregiver condition (Aguirre et al., 2019).

Interestingly, in the study of Nava et al. (2020), no effects of touch (stroking or tapping) on looking time to social stimuli relative to non-social stimuli were found (i.e., infants generally looked much longer at the faces than houses, regardless of touch stimulation). This is consistent with the results of Della Longa et al. (2017), where 4-month-olds' looking times when habituating to faces with averted gaze did not differ between groups who received concurrent stroking, tapping or no tactile stimulation. However, in the study by Della Longa et al. (2017), only the infants being stroked during the habituation procedure later demonstrated a recognition of the face they had habituated to: they looked significantly shorter at it when presented next to a novel face with averted gaze in a test phase (which is something 4-month-olds are normally not able to learn (Farroni et al., 2007)). Since this difference in face learning between infants who did and did not receive affective touch during stimulus presentation was not driven by differences in durations of visually attending to the stimulus, it must have been caused by qualitatively different processing of visual social information accompanied by affective touch (Della Longa et al., 2017).

Similarly, in a more recent study by Della Longa et al. (2020), 4-month-olds showed a preference for female faces (smiling, with direct gaze) with which they had earlier been presented while simultaneously being stroked; this was not the case when the faces were accompanied by non-affective brush tapping. As in the previous study, this effect was not mediated by differences in looking times to the stimuli between touch condition groups. The authors of the study concluded that affective touch carries an affective-motivational value increasing the salience of social cues – an effect that goes beyond enhancing infant attention (Della Longa, Carnevali, et al., 2020).

What could be the mechanism behind touch promoting learning of faces? One possibility is that affective touch would affect scanning patterns of faces, guiding infant attention towards regions constituting stronger social cues (e.g. eyes, mouth) as compared to regions not conveying as much social information (e.g. nose, cheeks). Thus, according to this view, even though affective touch does not affect total time spent looking at the face, it promotes more efficient encoding of the face information by enhancing the salience of the most informative face regions. This could happen through affective touch triggering the release of oxytocin (Vittner et al., 2017), which has been found to positively correlate with attention to mouth and eye regions in infants aged 5 months up to children aged 7.5 years (Nishizato et al., 2017). In adults, intranasal administration of oxytocin was also found to increase gaze to the eye region of human faces (Guastella et al., 2008).

If it is the case that affective touch enhances attention towards particularly socially salient regions within the face, then it should also bias infant attention towards social vs. non-social stimuli, when presented with various types of stimuli at the same time. This hypothesis has only been tested in newborn macaque monkeys (Simpson, Maylott, et al., 2019). After an interaction with a caregiver which did not involve any touch, but did involve mutual gaze, one-week-old macaque monkeys showed a preference for a non-social video (plastic bag floating in the wind) rather than a social video (conspecific producing an affiliative/positive facial expression), when presented with both of them, side by side on screen, at the same time. However, if the interaction with the caregiver included stroking, monkeys' preferences were shifted such that they attended equally to both types of videos. To the surprise of the authors of the study, this effect was present regardless of whether the preceding tactile stimulation was considered affective (stroking head and shoulders) or non-affective (stroking palms of hands and soles of feet). At the time, Simpson, Maylott, et al. (2019) hypothesised that the effects of touch on social orienting would be mediated by CT afferents, as these were not believed to be present in glabrous skin covering palms of hands and soles of feet – today we know that CT afferents are in fact present there, although much more sparsely (Watkins et al., 2020).

Determining whether it is narrowly-defined affective touch in the form of CT-afferent-targeted stroking that modulates infant processing of social information, or perhaps also other forms of affective touch, is a challenging task. For the sake of the present investigation, I do not differentiate between different types of caregiver touch; as we saw in Chapter 3, they are in fact significantly correlated with each other. I hypothesise that broadly-defined caregiver affective touch (including stroking, holding, kissing, etc.) modulates attention to social information in human infants: more touch from the caregiver would lead them to a larger looking preference for social vs. non-social stimuli, when presented with an array of objects (consistent with the findings of Simpson, Maylott, et al. (2019) with macaque monkeys).

Moreover, following Nishizato et al. (2017), I hypothesise that this preference is positively associated with infant salivary oxytocin levels. In the study by Nishizato et al. (2017), salivary oxytocin was interpreted as a trait, rather than a state measure; it was shown to be associated with children's age[17], and modulated by gene polymorphisms. Moreover, saliva samples were collected after the eye tracking session. However, considering the instant effects of affective touch on infant processing of faces (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020), and reports of touch increasing oxytocin levels on a short-term scale (Vittner et al., 2017), I hypothesised that oxytocin levels could also, to an extent, index infant state, which would be dependent on parental touch.

In Chapter 4, I demonstrated that neither reports of caregiver touch indicating long-term patterns of touching behaviours, nor touch observed during the parent-child interaction session predicted infant oxytocin levels. Nevertheless, it remains possible that salivary oxytocin, as a trait or a state measure, would predict infant attention to faces independently of caregiver touch, which is one of the hypotheses I test in the present study.

7.1.2. Present study

In this Chapter, I present results of a study investigating the associations between caregiver touch and infant attention to faces. Previous studies have shown that affective touch in the form of stroking does not increase absolute looking times to faces in infants (Della Longa et al., 2017;

[17] Although in Chapter 4 I also suggest that rather than a linear decrease in oxytocin levels with age, as argued by Nishizato et al. (2017), their data seems to be pointing to a decrease in oxytocin level variability; this is likely why in the much narrower age span of the present sample, no correlations between oxytocin and age were present

Nava et al., 2020). However, there is evidence that caregiver touch can bias attention towards social stimuli relative to attention to non-social stimuli in young children (Reece et al., 2016) and infant macaque monkeys (Simpson, Maylott, et al., 2019). It is possible that the failure to detect the effects of touch on infant attention to faces was due to a ceiling effect, i.e. when presented with a face, infants already exhibit a strong interest in it, as indexed by their looking times; therefore, it might be difficult to increase that interest even further. Perhaps assessing infant attention to faces in a scene where there are other, non-social stimuli competing for their attention would allow for this putative effect of touch to be observed.

Thus, I hypothesise that caregiver touch will predict infant attention to social stimuli, such that more touch will be associated with longer total duration of visually attending to social (vs. non-social) objects, when presented with both types at the same time (i.e., in one visual scene) in an eye-tracking task. Even though the literature suggests that this potential association could be mediated by oxytocin release, as reported in Chapter 4, no associations between caregiver touch and infant oxytocin have been found in this cohort. Nevertheless, I still test the hypothesis that infant mean salivary oxytocin levels would positively predict attention to socially-salient stimuli, as only one study (Nishizato et al., 2017) has reported a similar relation in infants. Additionally, in order to clarify whether salivary oxytocin, as a predictor of infant attention to faces, indexes an infant trait (i.e. a stable disposition), or also captures a transient state, I analyse the associations between the oxytocin measures taken at different timepoints (OT1 and OT2) and infant gaze behaviour.

7.2. Methods

7.2.1. Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in more detail in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7 months 21 days, 21 males and 18 females) and 11- to 13-month-olds (n = 32, M = 12 months 10 days, 17 males and 15 females) and their primary caregivers.

7.2.2. Measures

7.2.2.1. Face Pop Out task

In this task, infants were presented with complex visual arrays containing faces among 5 visual objects (Gliga et al., 2009). Sample slides can be seen in Figure 7.1.

Figure 7.1. Example slides from the Face Pop Out task

The infants were presented with seven different slides, for 10 seconds each. Their gaze was recorded with a 120 Hz Tobii x120 eye tracker (more details on the eye tracking procedure can be found in Chapter 2, section 2.2.3.2.).

The measure of interest was the proportion of time the infants spent looking at the face stimulus (i.e. infant's gaze was within the rectangular AOI around the face) with respect to the total time they spent looking at a slide. This proportion was computed for each slide where the infant gaze was on the screen for at least 67% of the time of its presentation (6.7 seconds). Considering the strong attention-grabbing properties of faces (Gliga et al., 2009), I wanted to only include those trials in which infants looked at the screen long enough for significant variability to occur, in order to avoid a ceiling effect. The threshold of at least 67% gaze data (or, maximum 1/3 missing data) per slide was an arbitrary, predefined criterion.[18] The proportions were averaged from between 1 and 7 slides per infant, to provide a more stable characterization of individual differences.

7.2.2.2. Caregiver touch

In Chapter 3, using a Principal Component Analysis approach on several measures of caregiver touch, both based on self-report (Parent Infant Caregiving Touch Scale, Social Touch Questionnaire, Touch Diary) and observation (derived from filmed parent-child interactions), I identified two dimensions that were labelled as Self-reported caregiver touch and Observed caregiver touch. In the present study, I use the factor loadings corresponding to the dimension representing self-reported touch (Dimension 1), and factor loadings corresponding to the dimension representing observed touch (Dimension 2) as predictors of infant attention to faces.

[18] In comparison, in a visual search task performed by toddlers, Portugal (2020) used an inclusion criterion of max. 25% missing data. Saez de Urabain et al. (2015) has argued that a predefined threshold is often a preferable approach to dealing with missing data.

7.2.2.3. Salivary oxytocin

Oxytocin levels in saliva samples collected during the dyad's visit in the lab were used in the analyses in the present study. Here, I employed the mean oxytocin measure (average from two samples collected during the visit, or just one sample if the other one was not available) to yield what I hypothesise would be a measure indexing an infant's stable disposition (following Nishizato et al., 2017), while also maximising the number of available data points in the analysis. Additionally, in order to clarify whether the associations between salivary oxytocin and infant attention are more constant (as in, salivary oxytocin would index an infant's stable disposition) or transient (salivary oxytocin indexing infant's temporary state), I also investigate the associations between the measures of oxytocin levels at the two timepoints (OT1 and OT2) and infant gaze behaviour.

A more detailed description of the oxytocin measurements can be found in Chapter 4.

7.2.3. Analytical approach

Firstly, I performed a linear regression to see if mean salivary oxytocin levels positively predict attention to face stimuli, as measured with the Face Pop Out Proportion score, which would corroborate the findings of Nishizato et al. (2017). Secondly, in order to determine the temporal characteristics of the oxytocin – attention to faces effect, for those infants for whom both salivary oxytocin data points (OT1 and OT2) were available, I performed a linear regression with both OT1 and OT2 as predictors. As OT1 was measured at the very beginning of the infant's visit in the lab (~60 minutes before the eye tracking session), and OT2 after about 40 minutes passed (and ~ 20 minutes before the eye tracking session), looking at the associations between these two measures and infant attention to faces could provide an insight into the temporal characteristics of the oxytocin – social attention effect. If OT2 shows a stronger association with the predicted variable, that would indicate that a transitory nature of this effect. However, if after controlling for OT1, the associations between OT2 and infant Face Pop Out score would not be present, this would indicate that the investigated effect is stable in time.

Secondly, I fitted a linear regression model to the Face Pop Out Proportion data, to test the hypothesis that caregiver self-reported and observed touch would positively predict infant attention to faces, independent of oxytocin levels.

Next, I fitted another linear regression model, which included interaction terms (Self-reported touch x Age group, and Observed touch x Age group) to test whether the association between caregiver touch and infant attention to faces is moderated by age.

7.4. Results

7.4.1. Descriptive statistics

Sixty-four infants contributed Face Pop Out Proportion scores (thirty-three 6- to 8-month-olds and thirty-one 11- to 13-month-olds), with data from seven participants missing because they did not participate in the eye-tracking session at all due to fussiness. Infants contributed data from an average of 4.4 slides (SD = 1.9): 4.6 (SD = 2.1) in the 6- to 8-month-olds group, and 4.2 (SD =1.7) in the 11- to 13-month-olds group. Mean Face Pop Out Proportion Score in the entire sample was 0.48 (SD = 0.16), meaning that when looking at a slide, on average, infants spent 48% of the time looking at the face. In the 6- to 8-month-olds group the mean was 0.50 (SD = 0.17), and in the 11-13-month-olds group it was 0.46 (SD = 0.14). The difference in Face Pop Out Proportion scores between the two age groups was not statistically significant (t(62)

= 0.88, p = 0.38). Scatter plots of Face Pop Out Proportion scores per age group are depicted in Figure 7.2.

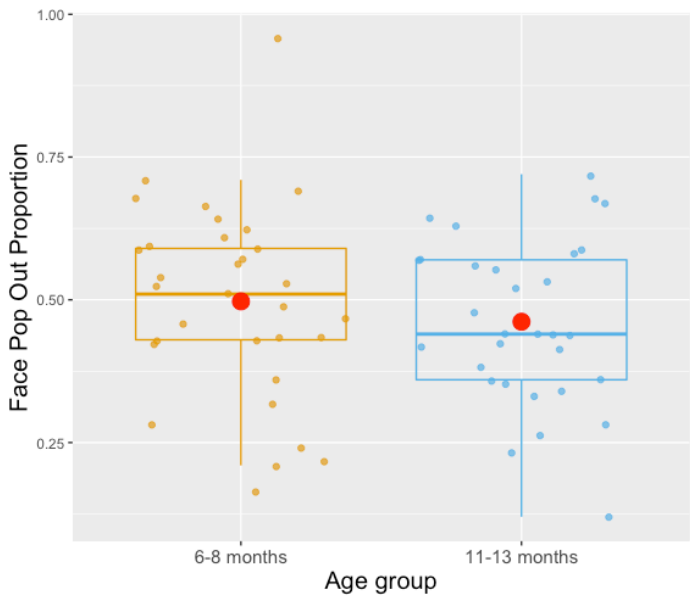

Figure 7.2. Boxplot showing the Face Pop Out Proportion scores in both age groups. All individual data are represented by points. Horizontal lines within boxplots indicate the median value, while red dots represent mean values.

Forty-eight infants contributed mean oxytocin data (twenty-eight 6- to 8-month-olds and twenty 11- to 13-month-olds; more detailed description of the oxytocin data can be found in Chapter 4). Forty infants contributed OT1 data, and thirty-nine contributed OT2 data; both OT1 and OT2 data were available for thirty infants. Self-reported and Observed touch data were available for all infants (more detailed description of the caregiver touch data can be found in Chapter 3).

7.4.2. Oxytocin-attention to faces association

Based on Nishizato et al. (2017), I did not have any reason to suspect that the association between oxytocin and attention to faces would be affected by infant age, so for this analysis, I pooled the data from both age groups. The linear regression model predicting Face Pop Out

Proportion scores with mean salivary oxytocin was significant ($F(1, 42) = 4.79$, $p = 0.034$, $R^2 = 0.10$). This corroborates findings from previous studies showing a positive association between salivary oxytocin and social attention (Guastella et al., 2008; Nishizato et al., 2017). The relationship between mean oxytocin levels and Face Pop Out Proportion is depicted in Figure 7.3.

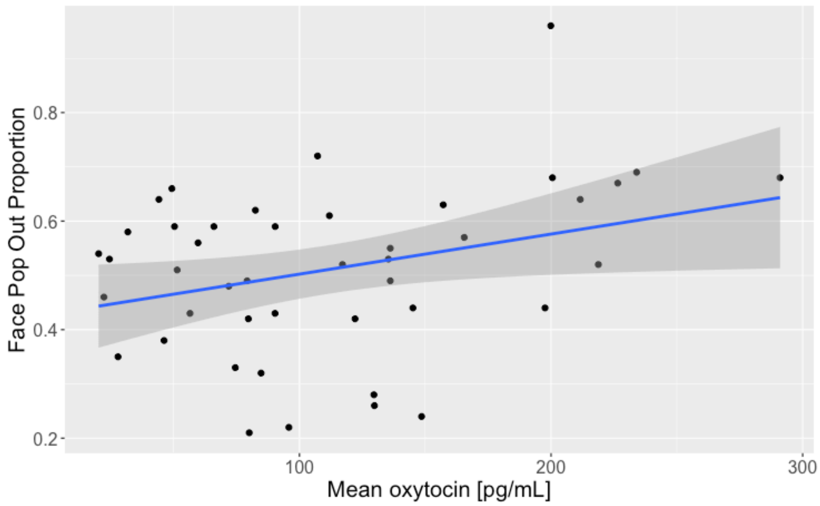

Figure 7.3. Relationship between mean oxytocin [pg/mL] and Face Pop Out Proportion

In order to determine whether the associations between salivary oxytocin levels and infant social attention are a stable association, as argued by Nishizato et al. (2017), or rather a transitory effect (which would support the possibility of the instant effects of affective touch on social information processing reported in previous studies being mediated by oxytocin), I fitted a regression model with OT1 and OT2 as predictors to the data of a subgroup of participants who had OT1, OT2 and Face Pop Out Proportion score data available ($n = 26$). The results are shown in Table 7.1. Although the model did not quite reach statistical significance ($p = 0.093$), OT1 ($\beta = 0.441$, $t = 2.169$, $p = 0.041$), but not OT2 ($\beta = -0.026$, $t = -0.127$, $p = 0.900$) turned out to be a significant predictor of the Face Pop Out Score. These results indicate that when controlling for baseline levels of salivary oxytocin, oxytocin levels measured closer in time to performing the Face Pop Out task are no longer associated with infant attention to faces. Such pattern of results is consistent with the idea that the association between oxytocin and infant attention to faces is a stable effect (Nishizato et al., 2017).

Table 7.1. Linear regression model predicting Face Pop Out Proportion score with OT1 and OT2

Predicting Face Pop Out Score with OT1 and OT2			
$F(2, 23) = 2.638, p = 0.093, R^2 = 0.187$			
Variable	**Standardized beta**	**t**	**p**
OT1	0.441	2.169	0.041
OT2	-0.026	-0.127	0.900

7.4.3. Self-reported/Observed touch – attention to faces association

A linear regression model predicting Face Pop Out Proportion scores with Self-reported Touch (PCA Dimension 1) and Observed touch (PCA Dimension 2) was fitted to the data of both age groups pooled together, to see if caregiver touch predicted infant attention to faces across infant ages, and if that effect was specific to long-term patterns of affective touch, or pertained to short-term non-affective touch as well. The results are shown in Table 7.2 (left). The model was not significant, indicating that in infants aged 6 to 13 months, caregiver touch, self-reported or observed, does not predict attention to faces, contrary to the hypothesis.

In order to further investigate if there was a significant interaction with age group, another linear regression model was fitted to the data, with Self-reported touch x Age group and Observed touch x Age group interaction terms. The results are shown in Table 2. (right). The model was not significant (specifically, the interaction terms were not significant either), indicating that age group did not moderate the association between caregiver touch and infant attention to faces.

Table 7.2. Linear regression model predicting Face Pop Out Proportion scores with Self-reported Touch and Observed touch (left) and linear regression model predicting Face Pop Out Proportion scores with Self-reported Touch, Observed touch and Self-reported Touch x Age Group and Observed Touch x Age Group interaction terms

Predicting Face Pop Out Proportion with Self-reported Touch and Observed Touch			
$F(2,61) = 0.190, p = 0.827, R^2 = 0.006$			
Variable	**Standardized beta**	**t**	**p**
Self-reported Touch	-0.053	-0.411	0.682
Observed Touch	-0.063	-0.493	0.624

Predicting Face Pop Out Proportion with Self-reported Touch, Observed Touch, Self-reported Touch x Age Group and Observed touch x Age Group			
$F(2,59) = 0.288, p = 0.885, R^2 = 0.019$			
Variable	**Standardized beta**	**t**	**p**
Self-reported Touch	-0.011	-0.063	0.950
Observed Touch	0.033	0.194	0.847
Self-reported x Age Group	-0.049	-0.276	0.783
Observed Touch x Age Group	-0.145	-0.861	0.393

7.5. Discussion

Contrary to what I hypothesised, caregiver touch did not predict infant attention to social stimuli; i.e., when presented with multiple non-social and social objects, infants receiving more touch (as observed and self-reported by their caregivers) were not more likely to look longer at social stimuli. This lack of association was the case regardless of infant age. This finding does not support the hypothesis that caregiver touch affects infant distribution of attention in a way that would bias it towards socially salient stimuli. However, it adds to the modest body of research demonstrating the lack of effects of affective touch on overt signatures (i.e., looking times) of infant attention to faces (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020).

It has to be noted that the measures of caregiver touch used in the analyses as predictors, Self-reported Touch (PCA Dimension 1) and Observed Touch (PCA Dimension 2), were a combination of different measures of caregiver touch collected in the study. My interpretation of the two dimensions, based on factor loadings yielded by the PCA analysis and correlations with age, resulted in the labels of Self-reported and Observed touch; it has to be noted however, that Dimension 1 has stronger loadings of measures of affective touch, and touch employed in infant-focused situations, while Dimension 2 mostly represents touch observed during interactions, and likely captures better non-affective, instrumental touching.[19] As argued in Chapter 4, I believe this characteristic is a consequence of what these types of measures are capable of capturing, but it also introduces a potential confounding factor where Dimension 1 represents more habitual, long-term patterns of affective caregiver touch (which could have long-term effects on infant social attention), while Dimension 2 mostly indexes the instrumental touch the infant received before performing the task (which could have more time-locked, instant effects on infant social attention). As such, it could be argued that Dimension 2 could have correlated more strongly with infant attention during the session, as the studies demonstrating the effects of touch on infant social information processing all focused on its short-term effects (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020). However, given that I did not find associations between the Self-reported touch and Observed touch dimensions and infant attention to faces, it seems like neither long-term or short-term effects of caregiver touch were present.

As discussed in the introduction, the main reason I suspected that caregiver touch would predict infant distribution of attention was because several studies have shown that touch affected infant processing of social information without affecting total looking times at social stimuli (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020). While the present study did not corroborate that these effects on social information processing could have been mediated by qualitatively different scanning patterns (i.e. more attention directed to more socially relevant cues), it remains possible that those putative differences in scanning patterns were more nuanced than a simple social/non-social distinction. As such, it is possible that they were not observable in

[19] See Table 3.4. in Chapter 3 for detailed factor loadings of the two dimensions

the present study, and could be better captured in a study investigating distribution of attention within a face (for example, attention to eyes and mouth in comparison to attention to the rest of the face, or fixation durations in different face areas etc.). Such a possibility is consistent with the original hypothesis that the effects of touch on infant processing of faces would be mediated by oxytocin, shown to associate with attention to eye and mouth areas in infants and children (Nishizato et al., 2017).

Indeed, even though I did not observe associations between caregiver touch and infant oxytocin (Chapter 4), I have confirmed the associations between oxytocin and attention to social stimuli in infants aged between 6 and 13 months. To my knowledge, this is the second study reporting such an effect, after Nishizato et al. (2017). Interestingly, when controlling for baseline oxytocin, the association between oxytocin measured closer in time to performing the eye tracking task did not show an association with infant attention. This finding seems to be indicative of salivary oxytocin in infants being an index of a long-term disposition (or, a trait measure) rather than indexing a temporary state; in combination with the inconclusive evidence for touch affecting salivary oxytocin in infants discussed in Chapter 4, oxytocin makes for an unlikely mediator of short-term effects of touch on social attention in infants. However, more studies, including ones measuring oxytocin closer in time to measuring infant social attention, could shed more light on the topic.

In the next chapter, I used electrophysiological measures to study the associations between caregiver touch and infant processing of social stimuli.

Chapter 8

Caregiver touch and infant neural correlates of face processing[20]

[20] The study presented in this Chapter was originally designed to serve as a pilot study for another experiment. However, data collection for the target experiment had to be terminated after only having collected data from three participants, due to the COVID-19 crisis.

8.1. Introduction

In the previous Chapter, I presented an investigation into whether the amount of caregiver touch an infant receives is positively associated with their attention to social stimuli. I did not find that more touch (self-reported or observed) from the caregiver correlates with more interest in social, in comparison to non-social, stimuli, when presented with both types of stimuli at the same time, as measured with infant looking times. However, previous research has shown that affective touch affects processing of faces in ways which may be less overt than looking times (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020). Therefore, in the present Chapter, I look into neural correlates of processing faces in infants in relation to touch received from their caregivers, as a covert measure of attention and emotional response.

There are at least two potential mechanisms through which affective touch could affect infant response to faces. One possibility is that affective touch could have an impact on face processing through the rewarding value of touch (Croy et al., 2017; Löken et al., 2009). It has been well-documented that C-tactile targeted touch (gentle slow stroking) causes self-reported pleasant sensations in children and adults (Ackerley et al., 2014; Croy et al., 2017; Sehlstedt et al., 2016). In infants aged 1 to 4.5 months, tactile stimulation seems to reinforce the positive emotional value of facial and vocal expressions of an adult: rubbing and stoking combined with smiling and cooing causes infants to engage in more eye-contact with the adult, smile and vocalise more than smiling and cooing alone (Peláez-Nogueras et al., 1996, 1997). In a study by Della Longa et al. (2020), 4-month-olds showed a preference for a face they had habituated to while being stroked, over a face they had habituated to while being tapped with a brush or without any tactile stimulation.

These results point to the possibility that affective touch, particularly in the form of stroking, could add to a positive emotional response to a face stimulus. By pairing a face with a pleasant tactile stimulation, a connection between the two stimuli could be formed, resulting in the face being associated with a pleasant sensation. As a result, the face could be more memorable to the infant. This effect could be the basis of bonding; in fact, the notion that touch plays an important role in forming attachments is a popular idea, and not a particularly new one (Botero et al., 2019; Harlow & Zimmermann, 1959; Norholt, 2020).

However, the effects of touch on emotional face processing have been largely underexplored under strict experimental conditions, and several questions remain unanswered. For instance, if affective touch increases positive emotional responses to smiling faces (Peláez-Nogueras et al., 1996, 1997), how would it affect the emotional response to neutral, or frowning faces? Or, if the face is already a familiar one (e.g. the face of the mother), would touch affect an infant's emotional response to it?

The second possible mechanism through which touch could affect processing of faces is through increasing their salience. When touching co-occurs with a face, it could act as a signal enhancing the significance of the face; a cue indicating that there is something to be learned. In this regard, touch might resemble eye gaze in its effects on infant attention and learning (Farroni et al., 2007; Rigato et al., 2011; Senju & Johnson, 2009). Both direct eye gaze (see Senju & Johnson, 2009 for a review), and affective touch (Bennett et al., 2014; Gordon et al., 2013; Jönsson et al., 2018) have been found to increase activity in posterior superior temporal sulcus, across development (although it is not clear when exactly the sensitivity of this region to affective touch emerges – see Pirazzoli et al., 2018 and Miguel et al. 2017). Posterior superior temporal sulcus is a region known to play a crucial role in social perception and cognition (Deen et al., 2015), and its activation by both social touch and direct gaze indicates common neural underpinnings of their effects on social information processing. In the previously discussed study by Della Longa et al. (2017), affective touch mimicked the effects of direct gaze on face identity learning in 4-month-olds. Moreover, even though I did not confirm the effects of touch on salivary oxytocin (as reported in Chapter 4), oxytocin is known to modulate the salience and reinforcing nature of social stimuli (Young, 2013), and could also be involved in the touch – face processing effects.

It has to be noted that the two putative mechanisms described above are not mutually exclusive; in fact, it is likely that one reinforces the other. Increasing the rewarding emotional value of a face stimulus would also increase its salience, and lead to better learning. However, the salience of a face could also be enhanced without any effects on the emotional response. In order to disentangle the emotional and strictly salience-driven effects of affective touch, in the present study I chose to investigate two distinct neural signatures, derived from the electroencephalographic signal: *frontal alpha asymmetry*, believed to indicate an emotional response to a stimulus, and *frontal theta power*, thought to be a marker of learning and focused attention. Below, I briefly introduce the two neural signals of interest.

8.1.1. Frontal alpha asymmetry

Basing on numerous results of studies with adults, children and infants, Davidson (1993) proposed a model where left frontal brain activity, either as a state or a trait, indicates a propensity to approach or engage with a stimulus, while relatively greater right frontal asymmetry indicates a propensity to withdraw or disengage from a stimulus (Coan & Allen, 2004). An index most commonly used to capture this relative imbalance between in frontal activity is frontal alpha asymmetry.

Frontal alpha asymmetry is a measure derived from the electroencephalographic (EEG) signal. To calculate the asymmetry index, power in the alpha band (6-9 Hz in infants; see e.g. Bell & Fox, 1992; Crespo-Llado et al., 2018; Perone et al., 2020) in the signal coming from the left frontal electrodes is subtracted from the power in the alpha band in the signal registered by homologous right frontal electrodes. Activation and power in the alpha band are inversely related, and therefore negative asymmetry scores represent right asymmetry, and positive scores represent left asymmetry (Davidson & Fox, 1982; Hane & Fox, 2006).

This index can be calculated from resting state data, normally lasting a couple of minutes, in which case it is commonly treated as a trait measure. Frontal asymmetry assessed during resting state has been shown to have moderate stability between 6 to 12 months (Brooker et al., 2017), and between 10 and 36 months (Howarth et al., 2016), and it correlates with various temperamental characteristics, including positive/negative affectivity and sociability (Coan & Allen, 2004). However, it is also often used as a state measure (response to a certain type of a stimulus), calculated from signals lasting from 10 seconds to a couple of minutes and recorded during various tasks (Coan & Allen, 2004).

In 10-month-olds, right frontal asymmetry during stranger approach and a toy spider task was found to correlate with fearful behaviours exhibited during those tasks (Diaz & Bell, 2012), while increased left frontal asymmetry correlated with reaching for mother during a mother approach task (Fox & Davidson, 1987). Brooker et al. (2017) demonstrated short term (1 week) and long term (6 months to 12 months) stability of frontal asymmetry patterns during peek-a-boo and stranger approach. Right frontal activity in response to a video of a peer crying, and left frontal activity in response to a video of a peer laughing was observed in 8-month-olds, but the results were only statistically significant in the case of the right frontal activity (Crespo-Llado et al., 2018). During the Still Face Procedure (Tronick, 1989), in which the mother is instructed to maintain a neutral face and be emotionally unavailable (i.e., not to communicate with the infant in any way, verbally or non-verbally), both infants (aged between 8 and 12 months) and their mothers exhibited a rightward shift in frontal alpha asymmetry, indicating growing negative emotionality and desire to withdraw (Perone et al., 2020).

Frontal alpha asymmetry in infants was also found to be associated with maternal caregiving behaviours: 9-month-olds receiving low quality maternal behaviours (coded from interaction videos and including dimensions such as Sensitivity-Insensitivity, Degree of Availability) were significantly more likely to exhibit a pattern of right frontal asymmetry at baseline (recorded during a presentation of a metal bingo ring with colourful balls being spun by an experimenter), and also exhibited more fearful responses to "scary" masks (old man, clown) (Hane & Fox, 2006). Furthermore, greater baseline right frontal asymmetry was observed between 3 and 13 months of age in infants of depressed relative to nondepressed mothers (Dawson et al., 1999), which could have been mediated by maternal caregiving quality, shown to differ between depressed and nondepressed mothers (Humphreys et al., 2018), including differences in touch-related behaviours (Beebe et al., 2012). A recent study demonstrated associations between polymorphisms in a gene related to oxytocin function, and frontal brain asymmetry in response to faces in 11-month-olds, such that the genotype associated with reduced peripheral oxytocin levels exhibited a frontal brain activation pattern indicative of withdrawal in response to smiling faces (Krol et al., 2021). Although, to my knowledge, no study to date has investigated frontal asymmetry in infants in response to affective touch, in adults, massage with moderate pressure caused a shift towards left frontal activation from before to after the massage session, which was not the case for control groups receiving light pressure massage and vibratory stimulation (Diego et al., 2004).

However, in case of frontal asymmetry, it seems that there is more evidence supporting the notion of relative right frontal activation being indicative of a negative emotional response/withdrawal than relative left frontal activation being indicative of a positive emotional response/approach (Brooker et al., 2017; Crespo-Llado et al., 2018). In fact, some have argued that greater left than right frontal cortical activity might actually indicate both positively and negatively valenced approach (Harmon-Jones & Gable, 2018). Despite the decades of research on state frontal alpha asymmetry, the interpretation of this measure still seems to spark some controversies.

Nevertheless, , I hypothesise that caregiver touch would be positively associated with left frontal activity/decreased right frontal activity in response to faces, indicative of increased approach/decreased withdrawal, as measured with frontal alpha asymmetry.

8.1.2. Frontal theta activity

Oscillatory electrical brain activity spanning roughly between 3 and 6 Hz in infants (in adults, the range is 3.5 – 7.5 Hz; Koehler et al., 2009) has been labelled as theta rhythm (Orekhova et al., 2006); recorded prior to or during learning, it has been shown to be predictive of learning success (see Begus & Bonawitz, 2020, for a review).

Theta oscillations over the frontal recording site have been found to correlate with learning outcomes, both short-term (Begus et al., 2015) and long-term (Braithwaite et al., 2020; Jones et al., 2020). There is also evidence of an increase in visually-entrained theta oscillations over occipital regions in violation of expectation paradigms, likely indicative of active learning (Köster et al., 2019), however most research to date has focused on the frontal sites (Begus & Bonawitz, 2020).

Some have looked into change in theta power over time, while viewing a novel video: Braithwaite et al. (2020) found that in 6-month-olds, individual differences in the magnitude of theta power increase over the course of viewing the video predicted non-verbal cognitive ability measured at 9 months. Moreover, Jones et al. (2020) demonstrated that individual differences in theta power change while viewing a video at 12 months predicted verbal and nonverbal cognitive skills as late as 2, 3 and 7 years of age. These findings suggest that frontal theta, and particularly the increase in its power over the course of habituating to a novel complex stimulus, are a marker of cognitive processes, most likely underlying active learning and encoding of a stimulus.

Consistent with this interpretation are the results of Piccardi et al. (2020), who showed that in 10-month-olds, repeated presentation of the same cartoon video (up to 10 times) caused an initial increase in frontal theta power, followed by a decrease. Piccardi et al. (2020) suggested that this pattern reflects progressive encoding and depletion of information.

In a study investigating short-term predictive power of frontal theta activity during object exploration on later object recognition in 11-month-olds, Begus et al. (2015) found that an index of theta power during exploration of a number of non-social objects (calculated as theta power during exploration of two objects eliciting highest theta power relative to theta power during exploration of two objects eliciting lowest theta power for a given infant) predicted later recognition of the previously explored objects, as indexed by higher novelty preference in a looking-preference paradigm. Crucially, this predictive relationship was not mediated by the amount of time the infants spent looking at or manually manipulating the objects, thus making frontal theta a promising candidate for an index capturing individual differences in learning better than behavioural measures (Begus et al., 2015).

In the light of these results, and considering the effects of affective touch on learning of face identities (found to not be mediated by the duration of visually attending to the face; Della Longa et al., 2017), I hypothesise that the effects of caregiver touch on social information processing could be observed as a positive association between measures of caregiver touch and infant frontal theta activity.

8.1.3. Present study

The present study was designed to serve as a pilot study for a subsequent experiment investigating the immediate effects of stroking (vs. brush tapping and no touch) on infant neural correlates of face processing. As a pilot study, its aim was to identify stimuli eliciting highest right frontal asymmetry and lowest frontal theta power, to later examine if affective touch in the form of stroking could affect infant neural response which, under baseline conditions, would be indicative of withdrawal and less active learning. To this end, I chose to present infants with five different types of face stimuli: (1) pictures of unfamiliar women smiling (with direct gaze), (2) frowning (direct gaze), and (3) with a neutral expression (averted gaze), as well as (4) unfamiliar men with a neutral expression (direct gaze) and (5) familiar woman – mother – smiling (direct gaze). I predicted that the familiar woman (mother) smiling, and unfamiliar woman smiling would both elicit positive frontal alpha asymmetry scores (associated with approach), while unfamiliar woman frowning would elicit negative asymmetry scores (associated with withdrawal). Moreover, I expected that the unfamiliar woman with averted gaze, and the familiar woman (mother) smiling conditions would elicit lower frontal theta scores than the other conditions, which would be associated with less learning happening during viewing of the pictures from these two categories.

In the planned follow-up study, the infants would be repeatedly presented with the same face on a screen (chosen based on the criteria described above), accompanied by their caregiver stroking them on front upper body, tapping them with a brush, or not touching them at all, while their EEG activity was being measured. Immediately afterwards, there would be an eye tracking session where infants preference for the face they were familiarised with in comparison with a novel face would be tested. The hypothesis was that stroking, in comparison with brush tapping and no touch, would lead to better learning of the face, as indicated by higher frontal theta scores in the stroking condition during familiarisation phase. This relatively higher theta power would, in turn, positively predict more looking at the novel face in the eye tracking test phase (see Begus et al., 2015). Moreover, I also hypothesised that stroking would cause a shift towards left frontal asymmetry during the familiarisation phase, as compared with brush tapping and no touch conditions.

However, since the target study was not completed (due to the pandemic-related restrictions), I expanded the aim of the present study, by also investigating the long-term correlates of caregiver touch patterns and infant neural processing of faces. Two questionnaires measuring mothers' self-reported touch in everyday interactions with their infants (the PICTS) and their own attitudes and affects associated with social touch (the STQ) were collected from the participants (in Chapter 3 I demonstrated that these questionnaires map onto caregiver behaviours, as observed during parent-child interactions). These questionnaires were later used to predict infant neural processing of faces.

Even though the original predictions pertained to the immediate effects of affective touch on infant neural response to faces, I argue that there are reasons to hypothesise that long-term effects of caregiver touch on social information processing exist as well. In 5-year-olds, the frequency of maternal touch used during an interaction (assumed to be representative of everyday touching patterns) was shown to predict resting state activity in the so-called "social brain" areas, including posterior superior temporal sulcus, measured two weeks later (Brauer et al., 2016). This finding indicates that, at least in young children, the effects of affective touch on posterior superior temporal sulcus activity and, as a consequence, potentially also social perception and cognition, are present long-term. In infant macaque monkeys, extra handling led to improved memory of social stimuli and more positive response to a novel person (Simpson, Sclafani, et al., 2019). It is likely that consistent high use of touch, especially in the presence of others in the infant's visual field, could lead to developing fixed patterns of response to faces through reinforcing more positive emotional responses to others, and promoting encoding of social stimuli.

Therefore, I hypothesise that caregiver touch would be associated with infant processing of social stimuli (faces), as indexed by two markers derived from the EEG signal: frontal alpha asymmetry and frontal theta. I predict that more touch received from the caregiver will positively correlate with left frontal asymmetry/attenuated right frontal asymmetry, indicative of more positive emotionality/approach tendency. I also hypothesise that caregiver touch will positively correlate with frontal theta power, indicative of more active learning/efficient encoding of social information) in response to faces. Moreover, I explore the differences between these two EEG markers between different types of facial stimuli – familiar and unfamiliar, expressing different emotions.

8.2. Methods

8.2.1. Participants

A total of twenty-two infants between 6 and 7 months of age (mean age: 6 months 24 days, standard deviation: 10 days; 11 girls and 11 boys) and their mothers participated in the study. All infants were recruited from a volunteer database at the Birkbeck Centre for Brain and Cognitive Development, had gestational age between 37 and 42 weeks, and had no history of pre or perinatal medical complications. All infants included in this research were typically developing and therefore had no known developmental atypicality, based on parental reports at recruitment. All caregivers gave written, informed consent concerning the experimental procedure. Infants received a certificate and a t-shirt as a thank you for participation. Caregivers were provided with cash reimbursement for their travel expenses. The procedure was carried out in accordance with the ethical standards of the Declaration of Helsinki. Ethical approval was granted by Birkbeck, University of London, Department of Psychological Sciences Research Ethics Committee.

8.2.3. Stimuli

Experimental stimuli consisted of pictures of faces belonging to five different categories: unfamiliar woman smiling, unfamiliar man neutral expression, unfamiliar woman frowning, unfamiliar woman averted gaze and familiar woman (mother) smiling. There were six different pictures per category, except for the familiar woman (mother) smiling category, which consisted of only one picture, taken on the day of the visit. The pictures belonging to the unfamiliar woman smiling, unfamiliar man neutral expression and unfamiliar woman frowning were derived from the

Chicago Face Database (Ma et al., 2015). The pictures of women with averted gaze were custom taken for the purpose of the experiment.

The picture of the mother was taken shortly before the experiment. The mother was asked to put on a grey t-shirt, to match the clothing of the models in the other stimuli pictures. She was asked to keep her appearance (e.g. hair, glasses) the way she usually wears it around the baby, in order to maximise the familiarity aspect of the image. A couple of pictures were taken by the experimenter while the mother was encouraged to smile, and one picture with what the experimenter perceived as the most natural smile expression was chosen. The chosen picture was edited by the experimenter using Inkscape 0.92.5 and remove.bg software (the picture was cropped, the background was removed and the brightness was adjusted), and added to the battery of stimuli used in the experiment.

All the pictures were all 2444 pixels (wide) x 1718 pixels (high) in size. Example stimuli from each category are depicted in Figure 8.1.

Figure 8.1. Example stimuli from each category: (a) unfamiliar woman smiling, (b) unfamiliar man neutral expression, (c) unfamiliar woman frowning, (d) unfamiliar woman averted gaze, and (e) familiar woman (mother) smiling

8.2.4. Apparatus and procedure

The procedure was carried out during a single visit in the Birkbeck Babylab. Upon arrival at the lab, the mother-infant dyad was given some time to get acquainted with the surroundings, and the objectives and the course of the study were explained to the mother. Then, the mother was asked to pose for a picture, which would later be used in the experimental procedure among other stimuli. When the mother-infant dyad was ready to begin the testing session, they were invited to the EEG testing room.

The testing took place in a dimly lit room. Infants were seated in a high chair (see Figure 8.2.), approximately 60 cm from the screen (27 inches; width: 59.77 cm, height: 33.62 cm), with their mothers standing behind them. There were two computers in the experimental setup: one controlling the sequence and timing of stimulus presentation using custom MATLAB scripts, and another one, recording the EEG signal received from the amplifier with the use of Net Station (Electrical Geodesic). The stimulus presentation script sent event markers to the computer running Net Station. For better timing precision, a photodiode attached to the stimulus presentation screen also sent binary event markers to Net Station each time a stimulus appeared on the screen. The EEG signal was recorded from 124 channels of a 128-channel HydroCel Geodesic Sensor Net (four channels positioned on the faces were removed to improve the wearability of the net) that was connected to a NetAmps 400 amplifier (Electrical Geodesic) and referenced online to the Cz channel. Channel impedance was kept at or below 100 KΩ, and signals were sampled at 500 Hz. A video camera situated below the stimulus presentation screen recorded the infants' face and gaze behaviour, allowing online monitoring of infants' performance. The videos were saved and stored for offline behavioural coding.

Figure 8.2. Infants were seated in a high chair during EEG recording.

The experiment consisted of a presentation of five different stimuli blocks belonging to the five categories: unfamiliar woman smiling, unfamiliar man neutral expression, unfamiliar woman frowning, unfamiliar woman averted gaze and familiar woman (mother) smiling. Each block consisted of a 10-second-long full-screen presentation of a face belonging to a given category, preceded by a 3-second-long presentation of a non-social fixation/baseline stimulus (see Figure 8.3.). There was a total of nine different non-social static cartoon stimuli presented as the fixation/baseline.

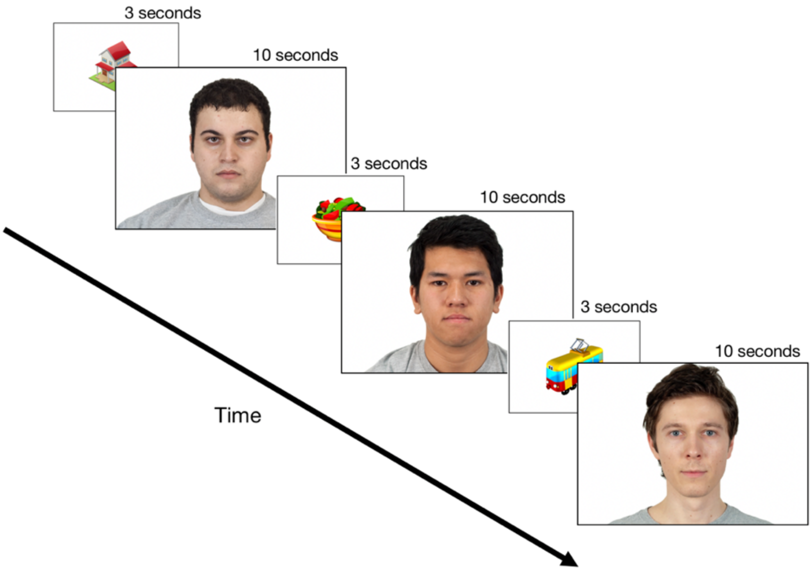

Figure 8.3. Representation of the sequence of events in a single block of the experimental paradigm. A 3-seconds-long baseline/fixation non-social cartoon stimulus preceded the presentation of each picture from the category of the running block, which lasted 10 seconds. Each block consisted of three baseline and three face presentations.

The five blocks were presented in a randomised order, and the order of the faces within a block as well as the non-social fixation/baseline stimuli within a block was also random. The fixation/baseline stimuli between blocks were presented for 5 seconds. After the five blocks were presented once, they were presented again in a newly randomised order, with new stimuli in each category (except the familiar woman (mother) smiling category, which always consisted of repeated presentation of the same picture). No face was presented more than once during the experiment, except the picture of the mother. The presentation of the stimuli was accompanied by instrumental music, to increase infants' engagement with the task. The total duration of the experimental procedure was around 7 minutes.

8.2.5. Questionnaires

After completing the EEG session, the infants and their mothers were invited back to the reception room, where the mother was asked to fill out three questionnaires: Parent-Infant Caregiving Touch Scale (PICTS; Koukounari et al., 2015), the Social Touch Questionnaire (STQ; Wilhelm et al., 2001), and Infant Behaviour Questionnaire -Revised Very Short Version (IBQ-R VSV; Putnam et al., 2014). The PICTS is a caregiver-report measure designed to assess frequency of tactile stimulation across multiple caregiving domains in infancy. The STQ is a questionnaire measuring an adult's attitudes and affects associated with social touch. The IBQ-R VSV is a caregiver-report measure of temperament for infants aged 3 to 12 months, consisting of three subscales: Positive Affectivity/Surgency (PAS), Negative Emotionality (NEG), and Orienting/Regulatory Capacity (ORC). The first two measures were used to assess caregiver use of touch in interactions with their infants, while the IBQ-R VSV was collected for possible follow-up exploratory analyses with regard to infant temperament and their response to faces.

As this study employed two touch-related measures, PICTS and STQ, I was interested in whether I could replicate the association between these two measures found in the previous study, where the two measures were negatively correlated. Indeed, I found PICTS and STQ scores to be negatively correlated in our sample ($r(20) = -0.45$, $p = 0.047$), further corroborating that parental general affects and attitudes regarding social touch were associated with less use of caregiver touch with the infant.

8.2.6. EEG recording and analyses

Videos of babies were visually inspected and coded for infant attention/fussiness in Net Station, adding markers to the EEG signal files, which were then exported to MATLAB. The remaining steps of EEG data pre-processing and analysis were performed using custom scripts in

MATLAB R2017a and the EEGlab toolbox (Delorme & Makeig, 2004). The recordings were re-referenced to an average reference. Continuous EEG data were filtered using a 1.0 – 49.0 Hz band-pass Butterworth filter. The segments where the infant was visually attending to the stimuli (as labelled by the markers from Net Station) were extracted and segmented according to stimuli condition, and then visually screened for motion and eye-blink artefacts. Segments with more than 8 channels with poor signal quality were manually rejected. For the remaining trials, spherical spline interpolation was conducted to replace bad channels data. Epochs of 1 s were then extracted from periods of continuous artefact-free data (any remaining samples were discarded; artefact-free segments were not concatenated but segmented separately). A total of at least 20 seconds of artefact-free data per each one of the six conditions (the five face conditions and the fixation/baseline condition) was required for the condition to be included in the analyses. The artefact-free segments were analysed with a Fast Fourier transform (FFT) with a 1-sec Hanning window and 50% overlap. Absolute power spectral density values for each segment were computed for the 5–7 Hz frequency band for the frontal alpha asymmetry analyses (Crespo-Llado et al., 2018), and 3–5 Hz frequency band for the frontal theta analyses.

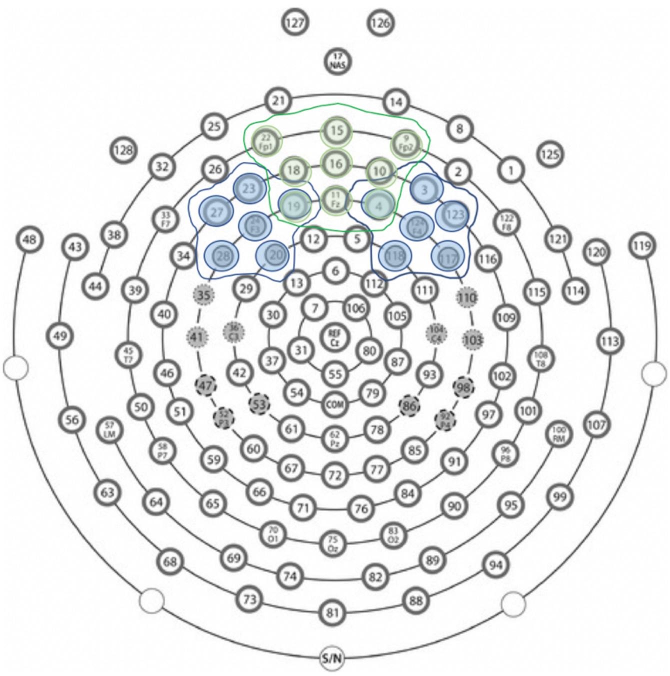

Figure 8.4. EEG electrode map, with marked groups of electrodes from which frontal alpha asymmetry scores (blue) and frontal theta scores (green) were extracted

8.2.7. Frontal alpha asymmetry scores

The electrodes which contributed to the frontal asymmetry scores are pictured in blue in Figure 8.4. The choice of the electrodes was motivated by previous studies demonstrating frontal asymmetry effects in these regions (Crespo-Llado et al., 2018; Perone et al., 2020). The analysis closely followed the steps described by Crespo-Llado et al. (2018). Frontal asymmetry scores for each infant in each condition were obtained by subtracting the left frontal hemisphere (F3) log-transformed alpha power from the right frontal hemisphere (F4) log-transformed alpha power values (i.e., ln(F4) − ln(F3)). Therefore, positive scores correspond to greater alpha power in the right hemisphere (or increased left activity interpreted as approach-oriented activity) while negative scores correspond to greater alpha power in the left hemisphere (or increased right activity interpreted as withdrawal-oriented activity).

8.2.8. Frontal theta scores

The electrodes which contributed to the frontal theta scores are pictured in Figure 8.4. in green. The choice of these electrodes was motivated by previous studies on frontal theta focusing on this site (Begus et al., 2015; Braithwaite et al., 2020). Frontal theta power was first computed in each condition, and then frontal theta scores for each face condition were calculated by subtracting log-transformed theta power in the fixation/baseline condition from log-transformed theta power in a given face condition, yielding a frontal theta score per participant per condition. This analysis was adapted from Begus et al. (2015).

8.3. Results

8.3.1. Descriptive statistics

Out of the twenty-two infants who participated in the study, sixteen contributed enough data (> 20 seconds) during fixation/baseline (MEAN = 49 s, SD = 24 s), eleven in the familiar woman (mother) smiling condition (MEAN =42 s, SD = 12 s), twelve in the unfamiliar woman with averted gaze condition (MEAN = 37 s, SD = 11 s), ten in the unfamiliar woman frowning condition (MEAN = 36 s, SD = 10 s), twelve in the unfamiliar man neutral expression condition (MEAN = 41 s, SD = 12 s), and twelve in the unfamiliar woman smiling condition (MEAN = 37 s, SD = 13 s). PICTS scores were missing for two participants and STQ scores for one participant due to experimenter error.

The average frontal alpha asymmetry scores were: -0.01 (SD = 0.20) in the familiar woman (mother) smiling condition, -0.06 (SD = 0.26) in the unfamiliar woman with averted gaze condition, -0.02 (SD = 0.26) in the unfamiliar woman frowning condition, -0.04 (SD = 0.29) in the unfamiliar man neutral expression condition, and 0.01 (SD = 0.26) for the unfamiliar woman smiling condition.

The average frontal theta scores were: 0.13 (SD = 0.42) in the familiar woman (mother) smiling condition, 0.13 (SD = 0.32) in the unfamiliar woman with averted gaze condition, 0.26 (SD = 0.20) in the unfamiliar woman frowning condition, -.02 (SD = 0.51) in the unfamiliar man neutral expression condition, and 0.10 (SD = 0.34) in the unfamiliar woman smiling condition,

The average PICTS score was 55 (SD = 5), and the average STQ score was 46 (SD = 10). The averages, medians and distributions of frontal alpha asymmetry scores and frontal theta scores are shown in Figure 8.5. and Figure 8.6., respectively.

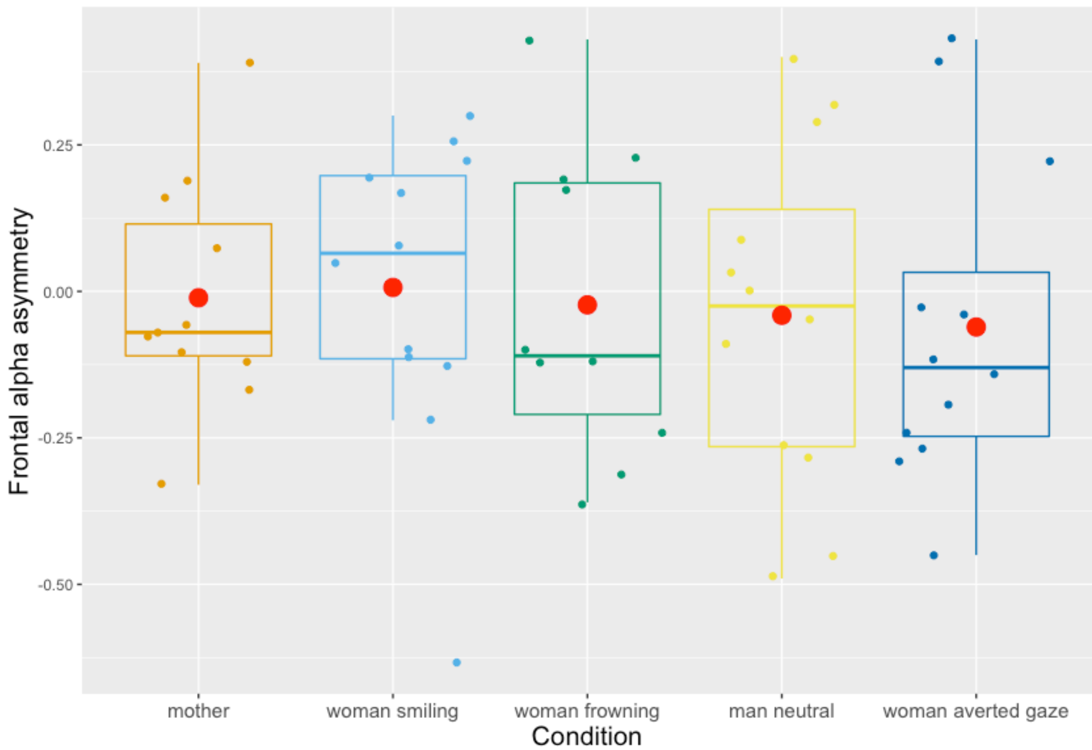

Figure 8.5. Boxplot showing frontal alpha asymmetry scores (left – right) for each face condition, in the order of expected decrease in alpha asymmetry scores All individual data are represented by points. Horizontal lines within boxplots indicate the median value, while red dots represent mean values.

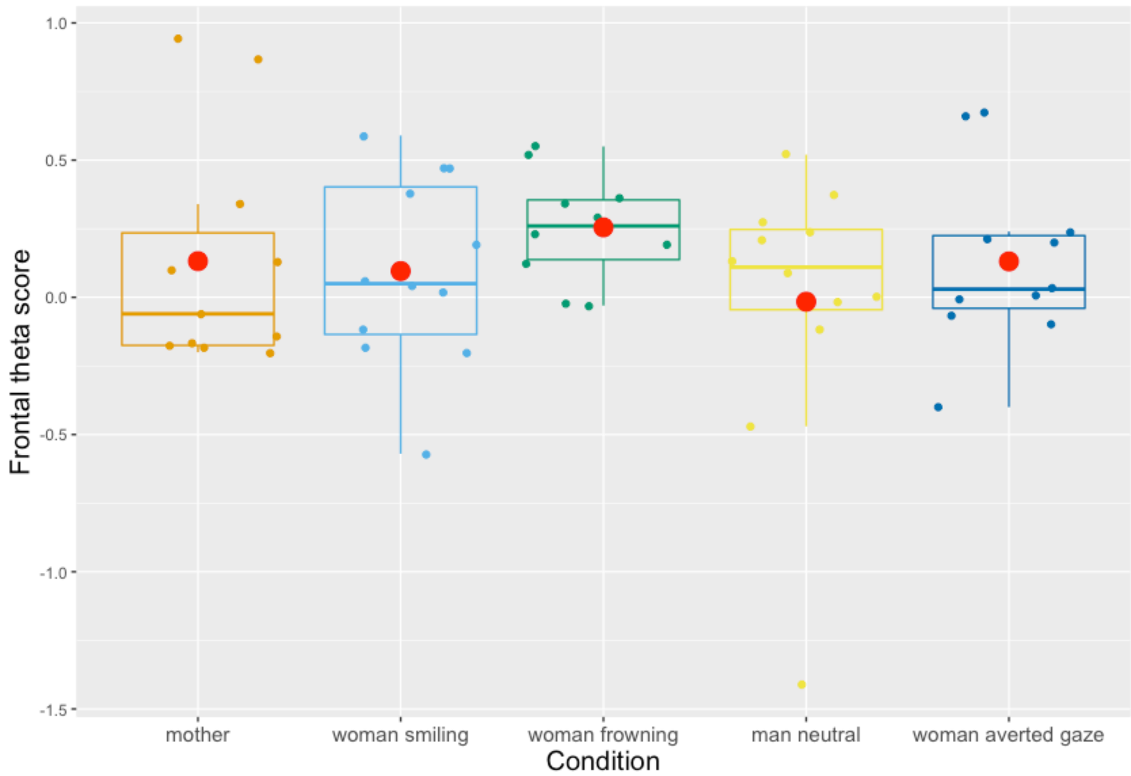

Figure 8.6. Boxplot showing frontal theta scores (condition – baseline) for each face condition. All individual data are represented by points. Horizontal lines within boxplots indicate the median value, while red dots represent mean values.

8.3.2. Frontal alpha asymmetry

A repeated-measures ANOVA was conducted on data from participants who contributed to all five conditions ($n = 9$), to investigate differences in frontal alpha asymmetry between conditions. The differences in frontal alpha asymmetry between conditions were not significant ($F(4, 32) = 0.26$, $p = 0.91$).

All but one condition (unfamiliar woman smiling) elicited a mean increased left relative to right absolute alpha power, indicating a withdrawal (rather than approach) response, but none of the frontal alpha asymmetry scores were significantly different from zero. The results of separate one sample t-tests were: $t(10) = -0.20$, $p = 0.85$ for the familiar woman (mother) smiling condition, $t(11) = -0.75$, $p = 0.47$ for the unfamiliar woman averted gaze condition, $t(9) = -0.28$, $p = 0.79$ for the unfamiliar woman frowning condition, $t(11) = -0.48$, $p = 0.64$ for the unfamiliar man neutral expression condition, and $t(11) = 0.08$, $p = 0.94$ for the unfamiliar woman smiling condition.

A composite score of general alpha asymmetry (average from up to five conditions) was computed for each participant. I hypothesised that more touch from the caregiver (as represented by higher PICTS scores) and caregiver's more positive attitudes and affects associated with interpersonal touch (as represented by lower STQ scores) would be positively associated with higher overall frontal alpha asymmetry scores (indicating increased approach/weakened withdrawal response to social stimuli). The PICTS scores did not show a significant correlation with the alpha asymmetry scores ($r(15) = -0.20$, $p = 0.48$). Surprisingly, the STQ scores were positively correlated with the frontal alpha asymmetry scores ($r(16) = 0.52$, $p = 0.037$), indicating that the more negative caregiver's attitudes and affects towards social touch were, the more positive infant's response to social stimuli was, as indicated by frontal alpha asymmetry scores.

Additionally, I looked into the associations between frontal asymmetry scores in response to the mother's face, with relation to the mother's STQ and PICTS scores, in order to investigate the possibility that more touch received from the mother would predict more positive response specifically to the mother's face. The associations between the frontal asymmetry scores and the PICTS scores ($r(11) = -0.02$, $p = 0.95$) and the STQ scores ($r(11) = 0.50$, $p = 0.12$) were not significant, indicating no effects of mother's touch on infant emotional response to her face.

8.3.3. Frontal theta

A repeated-measures ANOVA was conducted on data from participants who contributed to all five conditions ($n = 9$), to investigate differences in frontal theta scores between conditions. The differences in frontal theta scores between conditions were not significant ($F(4, 32) = 0.22$, $p = 0.93$).

In order to investigate whether any of the face stimuli caused a significant increase in theta power from baseline, a series of separate one sample t-tests was conducted. Only frowning faces caused a significant increase in theta from baseline ($t(9) = 4.08$, $p = 0.003$), indicating that when viewing frowning faces, infants' learning was increased from baseline. Smiling faces ($t(11) = 0.98$, $p = 0.35$), male faces ($t(11) = -0.103$, $p = 0.92$), faces with averted gaze ($t(10) = 1.37$, $p = 0.20$) and mother's face ($t(10) = 1.05$, $p = 0.32$) did not cause a relative theta power increase which would differ from zero.

A composite measure of general frontal theta score (average from up to five conditions) was computed for each participant. I hypothesised that more touch from the caregiver (as represented by higher PICTS scores) and caregiver's more positive attitudes and affects associated with interpersonal touch (as represented by lower STQ scores) would be positively associated with overall frontal theta scores (indicating more focused attention and learning of social information). Pearson correlations revealed results consistent with the predicted pattern, although not reaching statistical significance; using a one-tailed test, the correlation between PICTS scores and general frontal theta scores was $r(14) = 0.33$, $p = 0.13$, and between STQ scores and general frontal theta scores $r(14) = -0.40$, $p = 0.08$. These relationships are shown in Figure 8.7.

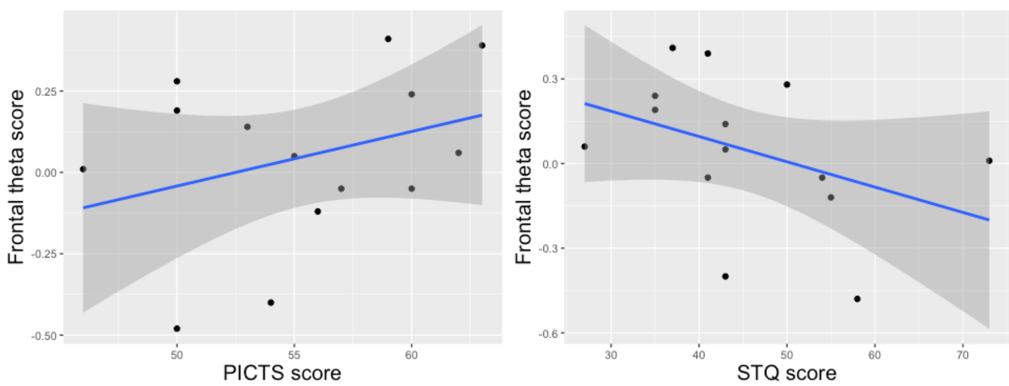

Figure 8.7. Relationships between PICTS scores (left) and STQ scores (right) and general frontal theta scores

8.4. Discussion

Frontal alpha asymmetry research has reported mixed results, with more evidence for an increased left relative to right absolute alpha power being associated with a negative/withdrawal response than the opposite being associated with approach response (Brooker et al., 2017; Crespo-Llado et al., 2018). In our study, none of the stimuli elicited a frontal alpha response which would be significantly different from zero, but the average response to all but one stimuli was an increased left relative to right absolute alpha power, suggesting negative/withdrawal response. It could be that the testing situation was generally a stressful situation for the infant to be in, and so caused a generalised negative response which spilled over most of the testing conditions. Given the controversies around the frontal asymmetry measure (Harmon-Jones & Gable, 2018), more established markers of infant emotional response might be better suited for the purpose of studying infant emotional processing of faces.

In this light, our findings showing that caregiver touch did not seem to make infants' response to faces (familiar or unfamiliar) more positive (or, in other words, associated with weakened withdrawal/enhanced approach) and, what is more, maternal anxiety and discomfort associated with social touch seemed to correlate with infant left frontal activity, indicative of approach/positive emotionality, has to be treated very cautiously. Nonetheless, a possible post-hoc explanation of this finding is that infants receiving less touch from their caregivers seek out social stimulation more. It is also possible that for associations between caregiver touch and infant emotional response to faces to exist, touch has to occur during or around the presentation of social stimuli.

With regard to the frontal theta measure, I found that only frowning female faces caused an increase from baseline, likely indicating enhanced attention and learning. This is consistent with earlier findings showing that negative facial expressions may be especially captivating to infants, particularly when coupled with direct gaze (Rigato & Farroni, 2013; Striano et al., 2006). Enhanced neural processing of such faces is likely driven by their novelty, as infants most likely have more experience with smiling or neutral faces (Rigato & Farroni, 2013). This finding not only corroborates the previous findings on infant processing of faces expressing various emotions, but also further establishes frontal theta as an index of active learning (Begus & Bonawitz, 2020).

In the present study, I found preliminary, weak evidence for caregiver touch showing long-term associations with frontal theta in response to faces, indicating more focused attention and learning of social stimuli. Although this finding was short of reaching statistical significance, it adds to the small body of evidence pointing to covert effects of affective touch on infant processing of faces (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020). If replicated, it would confirm that affective touch can modulate infant encoding of faces not just in an immediate fashion, but also long-term.

There are several limitations to the present study. Most importantly, the sample size (varying between n = 16 and n = 10, depending on the experimental condition), might not have been adequate for studying the putative long-term effects of caregiver touch. Moreover, my original hypotheses of the effects of affective touch on infant neural processing of faces were mostly based on studies investigating immediate effects of tactile stimulation, and had to be adapted. However, the results of the current study, although inconclusive, seem to support the notion that touch may enhance learning of faces. Further research on neural correlates of infant processing of faces with relation to caregiver touch – ideally both short- and long-term – is needed.

Chapter 9

General Discussion

9.1. General overview of the thesis

There are strong reasons to believe that caregiver touch plays a fundamental role in shaping infant cognitive development, and recent years have seen a significant increase in scientific interest in this area of investigation. This thesis aimed to address this topic by asking if the associations between naturally occurring variation in caregiver touching behaviours and infant outcomes in terms of broadly-defined exploratory behaviour could be observed in full-term infants, and what the mechanisms behind these putative associations could be. The present chapter discusses the main findings and implications of the research presented in this thesis. Limitations and future directions will also be discussed.

9.1.1. Measuring caregiver touch

Arguably, the primary reason why the impact of caregiver touch on various domains of infant development has been an understudied topic, is the challenge of measuring this means of interaction. The seminal rodent studies demonstrating the impact of naturally occurring variation in licking and grooming in offspring quantified these behaviours over extended periods of time, typically one hour per day over ten days (Caldji et al., 1998; Liu et al., 1997). Such long periods of observation are hard, if not impossible to achieve with human participants. Instead, human development researchers have quantified parental touching during single visits, over a period of a couple of minutes (Feldman, Singer, et al., 2010; Moreno et al., 2006). Alternatively, self-report tools such as questionnaires and diaries have been employed (Moore et al., 2017; Sharp et al., 2015), with hopes that they would yield representative estimates of longer-term caregiver behaviours.

However, to my knowledge, the extent of the agreement between the different measures of caregiver touch in terms of both general estimates of overall touch received by the infant, as well as estimates of the specific types of touch, e.g. stroking or holding, had never before been investigated. Yet, determining what the different measures are capable of capturing, and how well they capture those things, brings us one step closer to understanding the role of touch in early development.

Therefore, in Chapter 3, I described an investigation into the associations between different touch measures that have been employed in research on caregiver touch in infancy, not only comparing self-report and observational measures, but also between touch observed in different contexts, i.e. when the parent was focused on the infant, or simultaneously engaged in another activity.

There were several important findings coming from that study. Foremost, there is a moderate degree of agreement between questionnaire-measured caregiver touch, and touch observed during parent-infant interactions during free play. This finding is promising in two ways. Firstly, these two means of capturing parental touch seem to have been the most commonly employed approaches in previous research. Therefore, the interpretation of findings coming from studies employing these approaches is made easier by the fact that there is at least a certain degree of overlap in what was measured in terms of caregiver touch. Secondly, the fact that touch reported in a short one-off questionnaire, the PICTS, maps onto touch employed in interactions observed in the lab means that this very low-effort tool can be reliably used to provide estimates of parental touching behaviours. Not even a visit in a lab would be necessary, as the questionnaire can be easily filled out at home[21]. This may encourage developmental researchers to incorporate this measure in their studies, hopefully bringing about more research on the topic of touch in infancy.

Moreover, I found that observed, but not self-reported touch correlated with infant age: the older the infants were, the less touch their parents employed during interactions in the lab; this was not the case for self-reported measures of caregiver touch where no associations between age

[21] This may be particularly important in circumstances when a visit in a lab is impossible, for instance – during a pandemic-related lockdown (currently in place as I am writing these words).

and touch were found. Thus, researchers interested in developmental dynamics of caregiver touching behaviours may not find questionnaires or diaries particularly useful; yet, these measures might be especially informative about stable patterns of touch and parental beliefs about their use of touch. Self-report measures also seem to be more informative than measures derived from parent-child interactions about specific types of touch, such as stroking.

Finally, there were significant differences, both quantitative and qualitative, in observed caregiver touch between infant-focused (free play) and non-infant-focused (conversation with the experimenter) parent-child interactions. Self-reported touch measures were more strongly associated with touch during infant-focused interactions, and thus provide a biased account of parental touching behaviours. Considering that non-infant-focused interactions likely constitute a large part of caregiver-infant daily life, this means that in order to obtain a full picture of caregiver touching behaviours, observation of parent-child interactions should be conducted across different contexts, and we should ideally aim to quantify how often parents engage in play relative to other interactions with the infant during the day. Alternatively, emerging technologies, such as smart-suits recording body contact (Yao et al., 2019) could be the future of touch research in infancy.

An examination of the dimensional structure of the data from all measures of caregiver touch yielded two dimensions, which, based on their loadings, I labelled as Self-report touch and Observed touch. The Self-report touch dimension was largely composed of self-report touch measures, and, to an extent, touch used during free play, likely capturing patterns of affective touch best. In turn, the Observed touch dimension was derived mostly from touch employed during a non-infant-focused interaction, and, partially, touch used during free play. Going forward, in the chapters that followed (with the exception of Chapter 8 which was based on a separate study) I used these two dimensions as the main predictors of infant hormonal and behavioural outcomes.

9.1.2. Caregiver touch and infant hormonal response

A prominent avenue of research on the effects of social touch across development has focused on the associations between touch and two hormones – cortisol and oxytocin. These two hormones seemed like possible mediators of the effects of caregiver touch on infant exploratory behaviour. Cortisol, through providing insights into infants long-term HPA-axis function and momentary arousal, which I hypothesised would predict infant novelty approach and sustained attention. Oxytocin, through potentially reflecting infant sensitivity to social cues, which I hypothesised would predict infant social attention.

While the relation between caregiver touch and infant cortisol has been relatively well-established (Feldman, Singer, et al., 2010; Vittner et al., 2017), most studies focused on infants born prematurely and touch-based interventions. Studies on oxytocin in infancy have focused on similar populations, and brought mixed results. Thus, in Chapter 4, before diving into the putative mechanisms of caregiver touch impacting infant exploratory behaviour, I first presented an investigation into the associations between caregiver touch and infant hormonal activity in terms of cortisol and oxytocin.

I found that caregiver touch was not associated with infant oxytocin levels. Neither long-term patterns of caregiver affective touch, nor touch received by the infant during the testing session seemed to be related with infant's oxytocin. Although, to my knowledge, this was the first ever investigation into the associations between infant oxytocin and naturally occurring variation in parental touching behaviours beyond the sixth month of life (as outlined in more detail in Chapter 4), the findings of the study added to the ambiguous pattern of results obtained by previous studies.

Caregiver touch received by the infant did not seem to affect infant's salivary oxytocin levels. An alternative hypothesis which I put forward in Chapter 4 – that infant oxytocin levels, indicating infant social motivation or orienting to social cues, could indirectly drive caregiver touch behaviours also did not find confirmation in the data collected.

With regards to cortisol, the results indicated that caregiver touch used during the session did not cause a decrease in cortisol, as was hypothesised. Moreover, parental touch was not negatively associated with infant mean cortisol, which would indicate prolonged effects on infant HPA-axis function; rather, I found that the Observed touch dimension was positively correlated with mean cortisol levels in the infant. Further investigation into this association revealed that higher cortisol levels in the infant *before* the parent-child interaction predicted more use of touch by the caregiver.

There are several possible interpretations of these findings. Firstly, it is possible that while touch-based interventions, such as baby massage or Kangaroo Care, have consequences on infant hormonal response, the amounts and types of caregiver touch typically occurring in parent-infant interactions are not sufficient to affect cortisol or oxytocin levels over investigated timescales. However, it might also be the case that I did not observe the hypothesised effects of touch on hormonal response because the infants participating in the study were full-term, and over the age of 6 months – a population very rarely featured in studies on caregiver touch. Potentially, the effects of touch on hormonal response could be most pronounced in the first weeks of life (Kaffman & Meaney, 2007), or in premature infants (Feldman, Singer, et al., 2010)

However, the finding that infant cortisol at the beginning of the session (indicating higher levels of arousal or distress) predicted caregiver touching behaviours during the session, shows that parents intuitively use touch to comfort their infants. The fact that I did not observe that the touch the caregivers employed would have effects on infants' cortisol levels at the end of the parent-child interaction might indicate that there might be additional factors moderating infants' hormonal response to caregiver touch. For instance, Crucianelli et al. (2019) showed that depending on their ability to understand infant's needs and desires, during a book reading interaction, mothers used touch with their 12-month-olds with varying levels of emotional contingency. Emotionally contingent touch was defined as "touch that is contingent with the infant's experience and elicits positive affect in the infant", while emotionally non-contingent touch was defined as "touch not contingent with the infant's experience (…) intrusive, awkward, overwhelming, rough touch" (Crucianelli et al., 2019, p. 5). Thus, I speculate that whether or not caregiver touch would elicit expected effects on infant hormonal response would be dependent on the coordination of parental touch, in terms of not just quantity, but also quality, with infant current needs. This could be true not just with regards to cortisol, but also oxytocin – as previously shown by Markova (2018) and discussed in Chapter 4, maternal attunement plays a role in infant oxytocin system function.

In fact, the idea that synchronisation between interactional partners – in particular, within a caregiver-infant dyad – plays a crucial role in the various neurobehavioural outcomes of the interaction has recently gained much attention (Markova et al., 2019; Nguyen et al., 2020; Schirmer et al., 2021). This avenue of investigation poses additional challenges to the study of caregiver touch, but it might prove to be the key particularly to understanding the specifically human aspects of this means of interaction.

Although I found no effects of caregiver touch on infant cortisol and oxytocin levels, it may still be possible that caregiver touch affects infant exploratory behaviours through other mechanisms. First of all, it was possible that the effects of caregiver touch were present in other indices of infant arousal, which were not captured in the study. Secondly, the effects of caregiver touch on infant exploratory behaviour might not have been mediated by the effects on arousal. Therefore, in the following chapters, I focused on infant exploratory behaviour and its relation with the amount and types of touch infants receive from their caregivers, both long-term and short-term.

9.1.3. Caregiver touch and infant information sampling strategies

Before examining the effects of caregiver touch on infant exploratory behaviours, it was important to improve our understanding of the information sampling strategies driving these behaviours. Animal research emphasised the effects of caregiver touch on offspring's response to novel objects and environments, as well as time spent exploring (Caldji et al., 1998; Guardini et al., 2016; Harlow & Zimmermann, 1959; Simpson, Sclafani, et al., 2019). I hypothesised that these aspects of exploratory behaviour could be translated to the dimensions of novelty approach and sustained attention in case of human infants. As typically developing human infants rely to a large extent on the sense of vision in the ways they gather information about the world (Aslin, 2007; Johnson, 2010), it was critical for me to understand whether the putative effects of caregiver touch on novelty approach and sustained attention would be limited to manual exploration (given that, inevitably, that was the focus of animal research), or if they could also be observed in the ways in which infants visually engage with novelty.

Since there has not been much research relating measures of exploratory behaviour collected in table-top, physical object tasks and screen-based, looking time paradigms, my aim was also to investigate if seemingly analogous measures such as e.g. time spent looking at a novel object on a screen, and time spent manually exploring a toy, would load onto common dimensions (in this example, the dimension of sustained attention), or if they would represent functionally different aspects of exploratory behaviour.

The study presented in Chapter 5 showed that the measures collected in table top, physical object tasks and eye tracking tasks did not load onto the two hypothesised dimensions, sustained attention and novelty approach. Rather, they seemed to be indicative of information sampling strategies specific to the mode of exploration – manual, in case of the toy exploration tasks, and visual in case of the eye tracking tasks. Therefore, instead of investigating the effects of caregiver touch on generally defined novelty approach and sustained attention, I had to look into the effects of caregiver touch on the collected measures independently. Would caregiver touch be consequential on infant manual exploratory behaviour, given the results of animal studies? Or would it affect infant looking behaviour, since this mode of exploration is arguably the most available one to human infants since early on in development?

In Chapter 6, I went on to examine the associations between caregiver touch, as well as infant cortisol, and infant information sampling strategies in toy and eye tracking exploration tasks. I did not find evidence for caregiver touch (self-reported or observed) being associated with various measures of infant sustained attention, with the exception of stroking received during the session, which correlated with infant sustained attention to a single object presented on a screen. There was weak evidence that self-reported caregiver touch predicted novelty approach, as measured by the number of objects looked at on a screen; this effect was most pronounced in the older age group (11 to 13 months of age).

Thus, contrary to my hypotheses, I did not confirm far-reaching effects, short-term or long-term, of caregiver touch on infant exploratory profile. The isolated pieces of evidence described above do not seem to form a consistent pattern, and thus do not allow for making strong conclusions about the role of caregiver touch in shaping infant exploratory behaviour, though they might still be informative for future research. One of the insights coming from this study is that even though animal research showed the effects of caregiver touch on manual exploration, in this study, I observed no such effects and instead, any hints of evidence pointed towards possible effects on visual exploration. It may be that rather than faithfully imitating tasks used in animal research, it would be beneficial to learn more about the effects of touch on visual exploration, as a particularly important mode of exploration in human infants.

Alternatively, it is possible that the effects of caregiver touch on infant cognitive development are more direct, and not mediated by exploratory behaviour. Aside from the effects of caregiver licking and grooming on HPA-axis activity in rodents, effects on hippocampal development, particularly, expression levels of receptors for stress hormones, have also been found (Hellstrom et al., 2012; Liu et al., 2000). Stress-related hormones such as cortisol have been implicated as modulating the effects of early life experiences on hippocampus and, consequently, learning and memory processes (Hoeijmakers et al., 2015). Moreover, the hippocampus also exerts a certain amount of control over HPA-axis activity (Jankord & Herman, 2009; Snyder et al., 2011). Thus, caregiver touch likely affects emotional and cognitive processes alike, and exploratory behaviour might not have to be the link between infant arousal and cognitive development, as I originally hypothesised.

Figure 9.1 summarises the originally hypothesised mechanisms behind the effects of caregiver touch on infant cognitive development with comments about the evidence found in the thesis, while Figure 9.2. depicts an alternative model, based on the hypothesis described above.

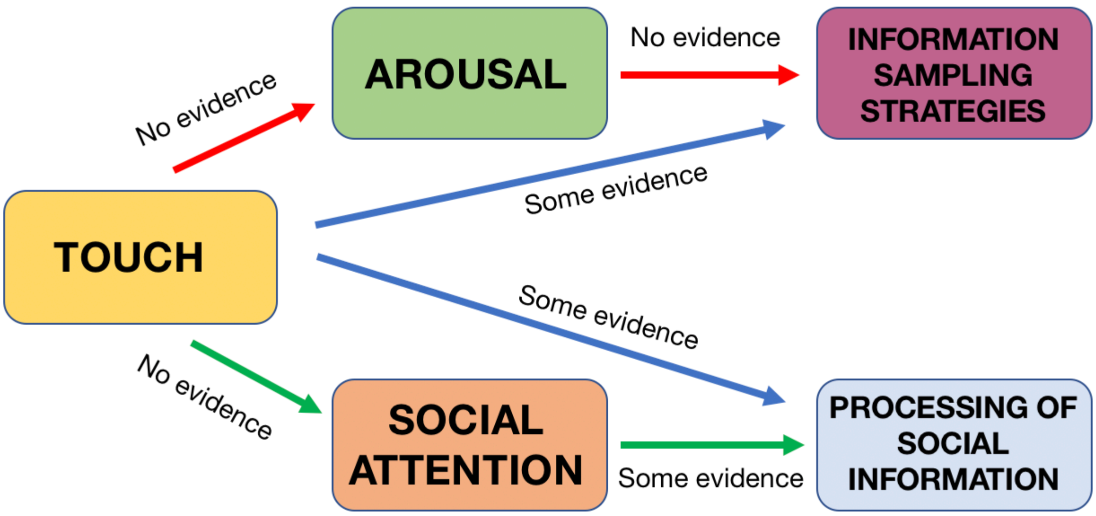

Figure 9.1. Original model of the effects of touch on infant cognitive development, with comments about the evidence (or lack thereof) as per research presented in the thesis

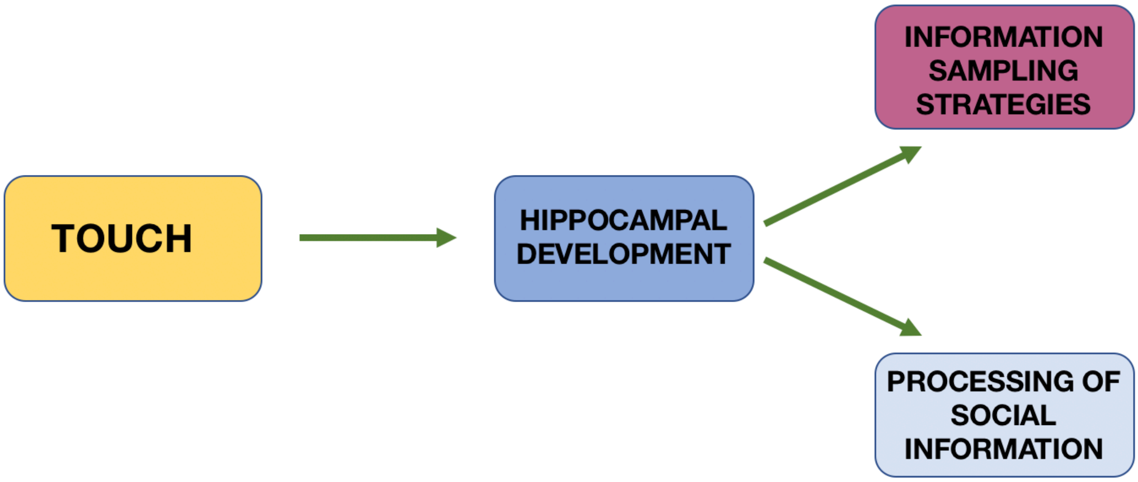

Figure 9.2. Alternative model of the effects of touch on infant cognitive development

Moreover, I found that infant arousal, measured with salivary cortisol, did not predict measures of infant novelty approach and sustained attention in any of the tasks. While this result could mean that infant arousal levels do not affect infant exploratory behaviour, it seems possible that salivary cortisol may not capture the changes in infant arousal in a way which would allow us to use it to predict infant behaviour. Research shows that the timescales at which arousal-attention effects occur are indeed measured in tens of seconds (de Barbaro et al., 2017). While cortisol may be an appropriate measure for investigating long-term effects on HPA-axis activity (Finegood et al., 2017), or a response to a stressor (Feldman, Singer, et al., 2010), in the present study it might have not allowed for testing arousal-attention effects. What is more, Wass et al. (2018) found that in 12-month-olds, increases in arousal were more long-lasting than decreases in arousal; any stress-buffering effects of touch that might have occurred in the present study (possibly observable in measures other than cortisol) could have disappeared by the time the infants were presented with the exploratory tasks. Moreover, the saliva sampling procedure itself could have acted as a stressor, elevating infant arousal shortly before they were presented with the exploratory tasks.

Yet, although I did not observe strong effects of caregiver touch on infant non-social exploratory behaviour, a possibility remained that touch could specifically affect infant exploration of social stimuli.

9.1.4. Caregiver touch and infant social attention

In Chapters 7 and 8, I focused on the putative effects of caregiver touch on infant attention towards social stimuli – faces. Previous research has shown that affective touch might have an effect on learning of face identities in infants (Della Longa et al., 2017), though this effect did not seem to be mediated by time spent visually attending to the face stimuli (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020). However, although touch did not seem to affect infant attention when the infant was presented with a single social stimulus, it seemed possible that touch could affect infant distribution of attention when presented with both social and non-social stimuli at the same time. More visual attending to social relative to non-social stimuli was shown to be correlated with salivary oxytocin levels in infancy and childhood (Nishizato et al., 2017). Given the hypotheses about the associations between caregiver touch and infant oxytocin activity, it followed that touch could potentially affect infant distribution of attention to social relative to non-social stimuli.

Therefore, in Chapter 7, I described an investigation into the associations between caregiver touch and infant looking behaviour when presented with slides depicting faces alongside non-social objects (such as cars, phones etc.). I hypothesised that more touch from the caregiver, both long-term, as well as short-term, would be associated with more attention to faces relative to the non-social objects. However, I did not find evidence of any associations between caregiver touch and infant social attention, as measured with looking time to social, relative to non-social stimuli. This result adds to the small number of published studies investigating the effects of touch on infant social attention. To put this finding in a broader context, the studies are summarised in Table 9.1.

The studies summarised in the Table 9.1. are quite heterogenous. Some are experiments on the concurrent or immediate effects of experimental manipulation of social and non-social types of touch on infant attention (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020), while others were correlational with longer timescales investigated (Tanaka et al., 2021 and the present study); the age groups range from 4 to 13 months. Nonetheless, all these studies looked into the effects of affective touch on a measure of social attention derived from looking times (to social, or social relative to non-social stimuli). The picture emerging from the research to date, including the current study, is that there is no evidence of such effects.[22]

Yet, I was still interested in whether infant salivary oxytocin would independently predict infant social attention; even if touch does not affect infant oxytocin levels, oxytocin could affect infant attention. I did indeed find that higher levels of salivary oxytocin in the infant predicted enhanced attention to the face, relative to the other stimuli. To my knowledge, this is only the second study showing this association in infants (the first one being Nishizato et al., 2017).

[22] I originally intended to perform a quantitative meta-analysis with these studies, but the lack of sufficient statistical data in some of the articles made it impossible.

Table 9.1. Studies on the effects of touch on infant attention to social stimuli

Study	Age of participants	Measure of social attention	Measure of touch	Results
Della Longa et al. (2019)	4-month-olds	mean looking time when habituating to a novel face	stroking vs. brush tapping vs. no touch during face presentation	no significant differences among conditions
Della Longa et al. (2020)	4-month-olds	mean looking time when habituating to a video of a novel face	stroking vs. brush tapping vs. no touch during face presentation	no significant differences among conditions
Nava et al. (2020)	4- to 5-month-olds	looking times to: a silent video of a woman talking, and silent video of a house with a moving door (presented separately)	stroking vs. brush tapping during video presentation	no significant type of touch x type of visual stimulation interaction
Tanaka et al. (2021)	6- to 8-month-olds	social and non-social images, side by side; Index of Preference for Social Scene (social scene)/(social + non-social scene); measured before and after a parent-child interaction	touch occurring in a parent-child interaction	no short-term effects of touch occurring during a parent-child interaction on the change in Index of Preference for Social Scene from baseline to after the parent-child interaction
Brzozowska et al. (Chapter 7)	6 – to 13-month olds	Face Pop Out proportion: (time looking at the face/total time spent looking at the slide)	touch occurring in a parent-child interaction/touch measured with self-report methods	no short-term or long-term effects of caregiver touch

Given that I found no effects of caregiver touch on measures of overt social attention in infants, and yet previous research indicated effects of touch on social learning, it seemed possible that touch could affect processing of social information in more covert ways. This is why I turned to examining neural correlates of face processing with relation to caregiver touch.

In Chapter 8, I described a small study investigating neural response, measured with electroencephalography (EEG), to faces varying in displayed emotion, gender, familiarity and gaze direction in 6-month-olds. In the study, I also collected information on caregiver touch used in everyday interactions with their infants, as well as caregiver attitudes and affects associated with social touch. I focused on two neural markers: frontal alpha asymmetry, thought to be associated with emotional processing and approach/withdrawal tendencies (Coan & Allen, 2004), and frontal theta, which indicates focused attention and learning (Begus & Bonawitz, 2020). I chose these two signals as I believed they would help me disentangle potential effects of caregiver touch on affective value of the face stimuli (which would be reflected in frontal alpha asymmetry) and on cognitive processing of the face stimuli (which would be reflected in frontal theta). I also investigated infant neural response as a function of the type of face stimulus which was presented.[23]

I found that everyday patterns of caregiver touch did not seem to be related to infant emotional response to faces (as measured with alpha asymmetry); this was true also when infants were presented with a picture of their mother. I did not find significant differences in infant frontal alpha asymmetry in response to different types of faces (depending on displayed emotion, gaze direction, familiarity and gender).

However, I found preliminary evidence that caregiver touch is related to infant focused attention to and learning of face stimuli: everyday patterns of caregiver touch (as measured with

[23] As described in detail in Chapter 8, the study was designed as a pilot for a follow-up study on the immediate effects of caregiver touch on infant neural correlates of face processing, which was not completed due to the COVID-19 pandemic.

the PICTS questionnaire) were positively correlated, while caregiver discomfort and anxiety associated with social touch (as measured with the STQ questionnaire) were negatively correlated with infant frontal theta in response to the face stimuli (the results were short of reaching statistical significance). If this finding is replicated, it would indicate that the amount of touch infants receive from their caregivers on an everyday basis might promote their focused attention and learning of faces; this would be consistent with previous research showing that affective touch enhances learning of faces in 4-month-olds (Della Longa et al., 2017).

Moreover, examining infant frontal theta as a function of the type of face stimulus, I found that frowning female faces caused a significant increase in frontal theta from baseline, indicating increased focused attention and learning (no such effects were found for the remaining types of face stimuli: smiling unfamiliar female face, smiling mother face, neutral male face and neutral female face with averted gaze). This result fits well with research showing that faces displaying negative emotions might be particularly salient to infants (Silvia Rigato & Farroni, 2013; Striano et al., 2006).

9.2. The Tanaka et al. (2021) study

In February 2021, shortly before the planned date of the submission of this thesis, a study directly relevant to my thesis was published. The study addresses many questions similar to the ones asked in this thesis (particularly Chapters 6 and 7) yet given the very recent publication of the study, integrating it throughout the thesis was not possible. I aim to provide here key insights from the study, and discuss how it compares with the research presented in my dissertation.

Much like the studies presented in Chapter 6 and Chapter 7, the main aim of the study by Tanaka et al. (2021) was to examine the associations between naturally occurring variation in caregiver touch and infant social engagement and object exploration. Although they did not collect measures of arousal or other biomarkers (such as cortisol or oxytocin), their hypotheses seem to have been based on similar theoretical premises to the research presented here. Table 9.2. summarises some of the main similarities and differences between the research presented in this thesis, and the Tanaka et al. (2021) study.

Besides the main theme, the similarities include the age range - 6-8 months (although in the studies presented in this thesis, a second age group, 11-13 months was included), sample size (~ 40 infants) and many of the methods used. Tanaka et al. (2021) investigated how differences in the amounts of affective touch occurring during a parent-child-interaction affected measures of infant exploratory behaviour: latencies to approach novel objects, as well as time spent manually exploring novel toys. Moreover, they looked into infants' social attention, as measured in an eye tracking task with social and non-social objects presented alongside. These are all measures which have also been used in the studies described in this thesis.

The main difference between our studies is that Tanaka et al. (2021) seemed to have used an experimental design in which parent-infant dyads were randomly assigned to "less physical contact" and "more physical contact" conditions before and after parent-child interactions[24], and measures of infant exploration were collected before, and after the interactions (while in the studies described in this thesis, measures of infant exploratory behaviour were only collected after the parent-child interaction, and there was no manipulation of parental touching behaviours). Similarly to the study described in Chapter 7, no associations between caregiver touch and infant social attention were found. However, contrary to our results, Tanaka et al. (2021) did find an effect of caregiver touch on infant non-social exploratory behaviour: infants in the "more physical contact" condition exhibited shorter latencies to touch novel objects relative to baseline after the interaction than the infants in the "less physical contact" condition; they also showed increased duration of object manipulation relative to the "low physical contact" group after the interaction.

[24] Tanaka et al. (2021) say that the parent-infant dyads were randomly assigned to "low social touch" or "high social touch" conditions pre-interaction, but the assignment procedure is not described; it is unclear how more or less social touch was elicited from the caregivers.

Table 9.2. A summary of similarities and differences between the main study in this thesis and the Tanaka et al. (2021) study

Characteristic	Tanaka et al. (2021)	Brzozowska et al. (Chapters 6 and 7)
Age	6- to 8-month-olds	6- to 8-month-olds (and 11- to 13-month-olds)
Nationality of participants	Japanese	German
Experimental manipulation of touch?	Yes, two conditions: low contact and high contact	No: quantification of naturally occurring touch
Measures of interest	Latency to touch novel toy, duration of manual exploration, looking to social relative to non-social objects (plus additional measures)	Latency to touch novel toy, duration of manual exploration, looking to social relative to non-social objects (plus additional measures)
Pre- and post-interaction measures of infant exploratory behaviour?	Yes	No
Infant on their parent's lap when performing the tasks?	Yes	No (in high chair during toy exploration tasks, and in a car seat during eye tracking tasks)
Effects of caregiver touch on infant social attention?	No	No
Effects of caregiver touch on latencies to touch novel toys and duration of manual exploration?	Yes: shorter latencies and longer durations of toy manipulation in the high contact condition	No

Yet, the results reported by Tanaka et al. (2021) have to be treated cautiously, as large and significant differences in latencies to touch novel objects between the two groups were already present at baseline, with infants in the "more physical contact" condition exhibiting longer latencies to touch novel objects at baseline (differing by even ~10 seconds between the two groups).[25] Thus, it is not clear if the observed differences in the changes in latencies to touch novel objects from baseline to after the interaction were indeed caused by the differences in the amounts of received caregiver touch, or by the initially much longer latencies (allowing for a larger post-interaction decrease) in the group of infants in the "more physical contact" condition. Still, with regard to the duration of object manipulation, differences between the two groups in the baseline durations did not seem to be a problem, therefore it appears that caregiver touch did have an effect on infants' ability to sustain attention on a novel object.

The Tanaka et al. (2021) study is a highly interesting piece of research due to its creative design and pertinent topic. Taken together with the other studies on the effects of affective touch on attention and learning in infancy which came out in the last couple of years (Della Longa et al., 2017; Pirazzoli, 2019), it seems that we may be witnessing a much needed boost of interest in the associations between touch and cognition in infancy, with hopefully many more studies to follow.

9.3. Limitations and future research

In order to improve our understanding of the topic of naturally occurring variation in caregiver touch and its consequences on infant broadly-defined exploratory behaviour, I employed a variety of approaches, which are associated with certain limitations.

Firstly, an important feature of the research presented in this thesis is that the focus was on *naturally occurring* variation in caregiver touching behaviours. Rather than trying to manipulate

[25] Detailed statistics, as reported by Tanaka et al. (2021): "The pre-test scores for Latency to First Touch were: for low saliency toys, M= 6.95 (SD = 5.31) in the Less PC condition, and M= 16.10 (SD = 11.12) in the More PC condition, t(38) = 3.23, p = 0.005; and for high saliency toys, M= 7.98 (SD = 5.60) in the Less PC condition, and M= 13.40 (SD = 12.44) in the More PC condition, t(38) = 1.82, p = 0.11 with Bonferroni correction." (Tanaka et al., 2021, p. 6)

the tactile stimulation received by the infant, or targeting infant populations with atypical touching experiences, I aimed to capture caregiver touching behaviours within the typical spectrum. This approach was motivated by the findings coming from animal research. Yet, aside from the various challenges associated with capturing naturally occurring variation in caregiver touching behaviours, described in detail in Chapter 3, there is an additional possible issue related with this approach in human research. While it seems fair to assume that a sample of animals participating in research would likely represent the full spectrum of touching behaviours (provided an adequate sample size)[26], it is a common problem in psychology research that samples relying on voluntary recruitment are inevitably biased (Nielsen et al., 2017). In particular with regard to research on touch-related behaviours, Field (2019) pointed out that the sample of people volunteering to take part in touch-focused studies might be confined to those who enjoy being touched and touching others. Although in the studies presented in this thesis the parents were not informed about the touch-focused aim of the research beforehand, they were, of course, informed about what the study entails, including the period of parent-child interaction observation. It is possible that the parents who decided to take part in the study were the ones who felt comfortable being observed during their interactions with infants, perhaps knowing that their behaviours were nothing "out of the norm". Thus, in the present thesis, it is imaginable that I did not capture the full spectrum of caregiver touching behaviours. However, it could also be argued that due to the collaboration with the industry partner, Procter & Gamble, I had access to a more representative participant pool. The concern raised here is in fact not specific to touch research, but rather common to studies investigating any aspects of caregiver behaviours. Although perhaps not a complete answer to this issue, emerging methods allowing for prolonged periods of monitoring of caregiver behaviours, such as smart suits (Yao et al., 2019; Zhu et al., 2015) could improve the validity of relevant measures.

[26] Although arguments could be made that lab animals are not representative of animals in the wild.

Secondly, an aspect of the studies presented in this thesis that needs to be addressed is the timing of the investigated effects. In my analyses, I attempted to examine both long-term effects of habitual patterns of caregiver touch, as well as short-term effects of touch received during interactions observed in the lab. Yet, it is unclear at what timescales the effects of touch on infant exploratory behaviour might occur. For instance, regarding short-term effects of caregiver touch, it is possible that any effects of the touch which occurred during parent-child interactions could have disappeared by the time the infants were presented with the exploratory tasks; this might also be true with regard to infant hormonal activity. It is also conceivable that what matters most is touch occurring *while* the infants engage in exploratory activities, which is a possibility I did not examine in the studies presented here. Future studies should ideally examine not just the amounts and quality of caregiver touch with relation to infant exploratory behaviour, but also the timing of these putative effects.

Another argument which should be raised here is the distinction between the effects of caregiver touch on non-social and social exploratory behaviour. A number of relevant studies which came out in the last couple of years specifically focused on the effects of affective touch on face processing in infants (Della Longa et al., 2017; Della Longa, Carnevali, et al., 2020; Nava et al., 2020). There are important arguments for focusing on how touch could affect social cognitive processes in particular. First and foremost, caregiver touch is inherently social – it occurs in the context of the caregiver-infant relationship. The role of touch in forming attachments and bonding is widely acknowledged (Dunbar, 2010; Harlow & Harlow, 1962; Williams & Turner, 2020). Specifically C-tactile targeted touch seems to well-suited to serve a communicative function (Crucianelli & Filippetti, 2020; Schirmer & Gunter, 2017; Walker et al., 2017). It follows that caregiver touch might be capable of shaping infant social cognition. Yet, the putative effects on social cognition are more often than not separated from its general effects of infant arousal and, potentially, attention. The fact that, as discussed earlier in this chapter, a number of studies failed to find effects of caregiver touch on infant overt social attention might indicate that the effects of caregiver touch on attention and learning are more general. In particular, enhanced learning of face identities when accompanied with affective touch (Della Longa et al., 2017), or the preliminary evidence of more focused attention to faces as measured with EEG in infants receiving higher levels of touch from their caregivers on an everyday basis, described in Chapter 8, would benefit from further exploration. Future studies should make a point of disentangling the specifically social, relative to general effects of caregiver touch on infant attention and learning.

The scope of the investigations presented in this thesis is quite broad, and yet there are several alternative avenues of research on how caregiver touch could shape infant cognition. As discussed earlier in this chapter, there are strong premises to investigate associations between caregiver touch and infant memory and learning, as mediated by the effects on hippocampal development. Furthermore, the intersensory redundancy hypothesis (Abu-Zhaya et al., 2017; Lew-Williams et al., 2019), described in detail in Chapter 1, seems like a promising framework particularly for studies on language development. Recently, Rocha et al. (2020) showed that the experience of being carried by the caregiver affects infant rhythm perception. While the avenue of research drawing from animal studies and the hypothesis of touch as a signal of environment quality (Meaney, 2001), which this thesis to a large extent represents, is certainly worth further investigation, it may be that the future of caregiver touch research are studies which fully embrace the specifically human aspects of both caregiver touching behaviours, as well as infant development.

Lastly, the studies described in the present thesis are correlational. Although there are strong reasons to hypothesise that there is a causal relation underlying the investigated associations between caregiver touch and infant exploratory behaviour (which I discussed in detail in Chapter 1), the studies presented here do not allow for making inferences about causality. I believe that in order to fully understand the impact of caregiver touch on developmental outcomes in infancy, we need a mix of correlational research, allowing us to capture parental behaviours in their natural form, as well as experimental research, enabling well-controlled manipulations of touch parameters, and causal inferences. In my original research plan my goal was to attempt both, yet, because of the COVID-19 pandemic, the plan was only partially realised. Perhaps one silver lining of the pandemic crisis in the context of this thesis is that the social distancing measures have caused many people to acknowledge the importance of touch, which might bring about more scientific interest in this often forgotten sense.

9.4. Conclusion

Despite much animal research indicating the key role of caregiver touch in the development of exploratory behaviour, very little research on this topic has been done with human infants. The studies presented in this thesis further our understanding of the role of caregiver touch in early development by providing a wide range of evidence on its associations with infant hormonal response and broadly-defined exploratory behaviour. A methodological contribution to the study of naturally occurring caregiver touch has also been made, by demonstrating the associations between self-report and observed caregiver touch measures for the first time. Although I found no evidence of the mediating role of cortisol and oxytocin on infant exploratory behaviour, there were some associations between caregiver touch and measures of infant information processing which would benefit from further investigation. Particularly, the possibility that the effects of caregiver touch on infant cognition are more direct, and not mediated by exploratory behaviour, deserves more scientific attention. The work presented in this thesis contributes evidence on a topic which has long warranted investigation, but had been largely neglected. Hopefully, more research will follow, bringing us further to fully understanding the impact of caregiver touch in early development.

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Appendix A: Caregiver touch and infant intermodal perception

This Appendix provides a synopsis of the Birkbeck MSc Psychology Research Dissertation titled "*The Measurement of Touch Relationships between Caregivers and Infants and the Effect of these Relationships on Intermodal Perception*" by Mary Bronks, which was supervised by Professor Denis Mareschal and co-supervised by myself. It provides further analyses of parts of the data collected for this PhD dissertation.

Background

The ability to integrate information across multiple modalities such as sight and sound develops over infancy and is crucial to understanding the world around us, especially in language learning. The objective of this study was to examine whether caregiver touch predicts infant intermodal perception, as an index of general cognitive abilities.

Participants

The participants in the current study were all the infant-caregiver dyads who participated in the main Caregiver Touch study, as described in Chapter 2 (section 2.1.), and consisted of two age groups: 6- to 8-month-olds (n = 39, M = 7;21, 21 males and 18 females) and 11- to 13-month-olds (n = 32, M = 12;10, 17 males and 15 females) and their primary caregivers.

Measures

The caregiver touch measures chosen were the Parent-Infant Caregiving Touch Scale (PICTS) and touch coded from videos of a nappy change task. The videos were coded for the total amount of touch given by the caregiver and also the number of non-functional touch events. Non-functional touch was defined as any event that did not directly relate to the nappy change, and the percentage total time the caregiver was touching the infant. The touch in the videos was coded as 'functional' meaning touch relating directly to the nappy changing task and 'non-functional' any other touch. Infants' intermodal perception was assessed with percentage congruent looking (looking time at the “multisensory ball”; see section 2.2.3.2.4. in Chapter 2) in the Multisensory integration task, averaged across up to 5 trials.

Results

In the sample of all infants from both age groups pooled together, an initial regression model with percentage congruent looking as the dependent measure and the touch measures, PICTS, percentage touch time, and the number of non-functional events as predictors was not found to be significant, $F(3, 53) = 1.10$, $p = .36$.

An exploratory investigation into the associations in both age groups separately revealed that a model containing all three touch measures significantly predicted the percentage congruent looking for the younger age group only: $F(3,23) = 3.14$, $p = .045$. The individual beta coefficients indicated that only percentage touch time ($t = 2.35$, $p = .03$) was a significant predictor in the model, non-functional events ($t= .65$, $p = .53$) and PICTS ($t = 1.73$, $p = .10$) were not significant. The model was not significant for the older age group ($F(3, 25) = .51$, $p = .68$).

Conclusion

The results point to the possibility that caregiver touch might be associated with infant ability to perceive intermodal events in the younger group. This is consistent with the idea that caregiver touch promotes infant cognitive development, although its impact might be most pronounced in early infancy. Alternatively, the measure of interest, percentage of time looking at a congruent stimulus, might have indexed cognitive ability in the younger group, while in case of the older infants, looking preferences could have been driven by other factors. Future research should examine more closely the associations between caregiver touch and intermodal perception, and the developmental timeline of these associations.